MAN'S INFLUENCE ON THE EARTH

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MAN'S INFLUENCE ON THE EARTH

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THORNTON BUTTERWORTH LIMITED
15 BEDFORD STREET, LONDON, W.C.2

First Published 1931

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CHAPTER I

INTRODUCTION

MAN'S action on Nature has two aspects: a geological and a biological one. The two are intimately connected. The biological effects of Man's activities include such matters as the destruction of species of animals and plants, a work that can never be undone; for we have reason to suppose that the conditions that produced a particular species, by evolution, will never recur exactly, and so a species once destroyed will never be reproduced. Man has also created new species and varieties of animals and plants, e.g. the many kinds of dogs, sheep, cattle, pigeons, fowls, and conservatory and garden plants. There is reason to suppose that without Man none of these would ever have existed. Moreover, the numbers, relative and absolute, of species of living beings have been greatly modified by him: where Nature intended a forest, Man grows corn and potatoes. Plants are enabled by his aid to grow in places naturally unsuited for

them; others, e.g. weeds, are driven out of places for which they are naturally fitted. The destruction of birds encourages insect-life until it becomes such a pest that Man has a struggle to curb it. Even in the world of microscopic creatures the effect is seen, and Man's influence is felt by bacteria and protozoa as much as by the largest living beings. In this book the geological aspect alone is considered: the biological aspect is worthy of a separate investigation.

Man's geological activities are primarily as an agent of Denudation; in which capacity he is probably more effective, in a thinly populated country, than even the sea itself. In addition, in mining operations he disturbs the flow of underground water, and causes subsidences. Among the mineral substances he produces are compounds unknown to Nature. Man disturbs the courses of rivers; fills lakes and makes new ones; checks or promotes sea-erosion; and modifies climates.

Some of these effects are geographical as well as geological in their nature, but the difference between Physical Geography and Geology is not easy to define. Indeed, some geographers, among them Professor G. G. Chisholm, admit that there is no real dividing-line between the two. This school of

geographers consider that it is convenient to restrict their subject to Anthropogeography, or the study of the effect on Man of local characteristics of the earth's surface, though some members of the school, such as Professors Davis and Penck, would include the effect of local characteristics on all living organisms. Much has been written about this aspect of the matter, but strangely enough the converse, i.e. the effect of Man on local characteristics, seems to have attracted scarcely any attention. There are accounts by Brunhes, Woeikof, Marsh, and others, of the results of irrigation, the cutting down of forests, tillage, etc., on the welfare of the human race, but I have been unable to discover any comprehensive account of the effect of Man on geographical or geological conditions.

Geology has suffered under the aspersion of being an inexact science, for as a rule its conclusions do not admit of the mathematical accuracy so highly esteemed by the physicist. However, the dictum that we cannot be said to know anything until we have measured it, applies to geology as much as to physics, and we should aim at obtaining as near an approximation to the true figures as circumstances permit. Many of the estimates of quantities here given

have probably not been attempted before, as, for instance, the total amount of rock mined and quarried in Great Britain, or the quantity of road-paving materials ground to powder by traffic; and such estimates are not supposed to be more than rough approximations to the truth. If investigators are led to criticize and strive to produce better estimates these first approximations will have served a useful purpose.

The apparently erratic manner in which Man interferes with Nature makes it particularly difficult to estimate the net result of his activities. His great engineering feats are so widespread that it would be a herculean task to sum up their total effect on Nature. It is wise, therefore, to limit the investigation to a definite area, such as Great Britain, which provides a reasonable chance of obtaining the necessary data. Even in this case it is very difficult to estimate quantities. This arises in part from the incessant changes in the form of published statistics and papers. Thus if we take the annual reports on Mines and Quarries, issued by the Home Office and afterwards by the Ministry of Mines, we notice new groupings every few years, so that it is impossible to distinguish any item for many years.

In the following chapters there is no mention of the effects of the Great War. This is partly because scarcely any data are available by which the geological effects could be measured, and partly because the destroyed lands were fortunately outside the area dealt with.

An important question that needs consideration is the effect of Man's geological activities on the estimates of geological time, since, if his activities are ignored, the present rate of denudation, on which estimates of the time-scale are usually based, will be quite misleading. Another even more interesting question is to what extent, if at all, Man's activities are in opposition to natural forces, and this is discussed in the concluding chapter.

Among the publications consulted are the Proceedings of the Institute of Civil Engineers, comprising more than two hundred volumes; Reports of Royal Commissions on Water Supply, Canals, Coast Erosion, Sewage, and Coal Supply; the Mineral Statistics issued annually by the Home Office and afterwards by the Ministry of Mines; the Census of Production issued by the Board of Trade; the volumes of *The Quarry*, *British Clayworker*, *Water*, and numerous other works. Previous books

dealing with the subject are few, the most important being *The Earth as Modified by Human Action*, by G. P. Marsh; the third and last edition being published in 1877. This book contains a great mass of information, but the greater part of it is devoted to the effects of the destruction of forests, and the geological aspect of Man's work is but briefly considered. The treatment, too, is scarcely scientific; for example, the author states that the making of the Panama Canal is impossible. Nevertheless, the book is a most important one, and apparently the only one on the subject in the English language. Sir C. Lucas, in his Presidential Address to the Geographical Section of the British Association in 1914, indicated the chief lines on which Man acts as a geographical agent; and Mr. H. M. Cadell has given an account of Man's work in transforming the Firth of Forth. In his *Text-Book of Geology*, fourth edition, 1903, Sir A. Geikie devotes three pages to a brief outline of the subject, and points to it as an important branch of geology worthy of investigation in the future. T. C. Chamberlin and R. D. Salisbury in their large text-book *Geology* devote less than two pages to "Man as a Geological Agency," and almost the whole of this brief notice refers

to Man's biological rather than his geological activities.

The size of the present work prevents more than a brief summary of the facts on which the conclusions are based. In the author's book, *Man as a Geological Agent*, published in 1922, the subject is treated much more fully and the methods by which the results here recorded were obtained are described. In that work also full references are given to all sources of information that have been used.

It is perhaps worth recording that the idea of this book was suggested by a passage in Huxley's *Evolution and Ethics*, which seemed to point to an apparent interference with Nature by Man. But before interference with Nature can be assumed to be more than trivial it is necessary to discover what Man actually does effect, and it is this question which is here investigated.

CHAPTER II

THE DENUDATION OF ROCKS BY EXCAVATION

THE final effect of subaerial denudation is the formation of a plain, apparently horizontal but in reality rising inland from the coast so gradually that water will just flow over it into the sea. Human denudation acts differently. In quarrying road-metal and building-stones the hardest rock, the bony framework of the land, is removed in preference to the soft clays and sands picked out by natural agents. Where Nature would leave a hill of hard rock, there Man leaves a hole. At other times it is soft rocks that Man removes; hence a characteristic difference between human and natural denudation is the apparent lack of plan in the former. Again, human denudation is localized: instead of a slice being planed off some considerable area and rounded contours left, Man digs here and there and leaves the surfaces of the land broken and angular. At the margin of the land he

often enhances the separation of land and water by dredging or embanking the shallow places: a swamp may be turned into dry land, or, on the other hand, a low-tide mud-flat is removed by dredging, and its site becomes permanently submerged.

A characteristic of human denudation almost unique is the removal of rock from below the surface of the land while leaving the surface itself undisturbed except by subsequent subsidence.

The greatest single feat of denudation ever performed by Man is probably the digging of the Panama Canal, where 200,000,000 cubic yards, largely of hard rocks, have been removed; but the greatest aggregate effect of human denudation is to be found in the countries most densely populated and most highly civilized, such as Western Europe and the United States of America. Here, too, we have the fullest information relating to the changes effected by Man. The United States have perhaps the most complete data, but the country has been much more recently settled than Great Britain, and is, moreover, so large, and has still such extensive areas sparsely inhabited, that it seems best to take Great Britain for detailed study.

Under excavation we have to consider:

(1) the materials removed from quarries, mines, and excavations of all kinds, and (2) the quantities dredged in rivers and estuaries.

For mines and quarries the annual volume issued by the Home Office, entitled *Mines and Quarries. General Report and Statistics*, and its successor issued by the Mines Department, is the most important source of information. For coal we also have the Reports of the Royal Commissions on Coal Supplies, and there are numerous other sources of information.

From the earliest times a certain amount of excavating must have been done by Man, but with the increase of civilization and population and the growth of industry the quantity has increased by leaps and bounds, so that the amount of denudation before the eighteenth century is very small compared with that effected since.

Considering, first, materials removed in mining operations, we find that in olden times coal was dug at the surface wherever it cropped out, but this coal was soon nearly exhausted, although even at the present day a little is occasionally got in this way, as e.g. during coal-strikes. As workable coal-seams range in thickness from 30 feet to as little as 1 foot, it is frequently necessary,

when the seam is thin, to remove much of the overlying and underlying strata. Moreover, the sinking of the shafts means the excavation of additional large masses of stone. The bulk of the materials removed in these ways is probably equal to half that of the coal.

Metalliferous mining in Britain is of great antiquity. Robert Hunt thought that it was 3,000 years old in this country, and that the bronze used by primitive man must have been obtained from the Indian Archipelago, from Spain, or from Britain. According to Julius Cæsar, although brass money and iron rings were in use in Britain in his day, the brass was all imported.

Blasting was first introduced into England by Prince Rupert, who employed German miners, probably between 1636 and 1645, to work the copper-mines at Ecton, Derbyshire. Previously the only way of getting the ore was by making a fire against the working-face in the evening. By morning the veinstuff was so loosened that it could be picked or wedged down.

It is common knowledge that tin has been mined in England since the days of the Phœnicians. Hunt thought it possible that the original stanniferous deposits of ancient Britain are now submerged, and he

pointed out that a survey of Edward IV gives twice as many acres to Cornwall as it now contains.

After the Roman occupation there is no evidence of mining for a long period. Throughout the Middle Ages European nations must have drawn tin supplies from this country. A considerable demand would be caused by the introduction of bells in churches in the sixth and seventh centuries. Bronze cannon were introduced in the thirteenth century, and pewter (tin and lead alloyed) in the fifteenth century.

It is uncertain when the working of iron was introduced into Britain. D. Mushet (*Papers on Iron and Steel, Practical and Experimental*) thinks it probable that the Phœnicians introduced skilled iron-workers. The remains of Roman workings are found in the Mendip Hills, Derbyshire, Yorkshire, Cheshire, Co. Durham, Northumberland, Cumberland and Lincolnshire. It is believed that improved methods of smelting were introduced by the Danes. Large heaps of scoriæ, called "Danes' cinders," are found in many places, with enough soil over them to grow large trees. Since then these "cinders" have been re-smelted.

The early process of smelting iron-ore was by a wind furnace, almost the same as

that at present used by natives in India and Africa. The ore was smelted on the mountain-side, in early times by wind-power, while later on the smelting was performed in valleys, in sites where water-power was available. Charcoal was used for smelting and the country, once covered with trees, become more and more deforested, until, in 1740, wood was so scarce that the industry was reduced to an output of 17,350 tons of iron for the whole of Great Britain.

W. S. Jevons, in *The Coal Question* (Edition 3, 1906), and R. Meade, in *The Coal and Iron Industries of the United Kingdom*, give the production of pig-iron in Britain as follows :

	Tons.
1740 production . . .	17,350
1788 ,, . . .	68,300
1796	125,079
1806	258,206
1825	581,367
1840	1,396,400
1847	1,999,608
1854	3,069,838
1860	3,826,750
1870	5,963,510
1880	7,749,230
1890	7,904,214
1900	8,959,691

According to Jevons the earlier figures are probably too high.

The introduction of coal gave a great impetus to the iron industry and led to the making of canals and tramways towards the end of the eighteenth century. Previously goods were carried by mules or pack-horses. For example, Jevons records that, in 1580, Sir Francis Willoughby built Woolaton Hall, Nottingham, of stone brought from Ancaster, in Lincolnshire, on pack-horses, which returned laden with coal in exchange.

The output of pig-iron in Britain has been calculated from the outputs given on page 19 for various years from 1740 to 1872, assuming the increase between the dates for which the output is given to be steady. The assumption is also made, on the authority of Berschlag, Vogt, and Krusch, that ore yielded about 35 per cent. of pig-iron before 1860 and about 40 per cent. from 1860 to 1890. These data give us the output of ironstone between 1740 and 1872. The outputs from 1873 to 1913 are taken directly from the Mineral Statistics. The total output from 1740 to 1913 inclusive was therefore about 982,524,000 tons of ironstone. This would imply about 332 million cubic yards of ironstone (of average specific gravity 4·017).

The proportion of ore mined to that

quarried is much less than formerly, owing to the opening up of the Mesozoic ores of the Midlands and Yorkshire. To arrive at the bulk of materials excavated about 50 per cent. must be added to that of the iron-ores to allow for waste materials.

Oil shale was at one time mined extensively at Burntisland, Fife, but more recently only in a triangular area to the west of Edinburgh. The output from 1873 to 1913 was 78,054,140 tons, and allowing for waste about 50 million cubic yards of rock has been mined.

Rock-salt is referred to on page 79.

Slates have been in use since the Middle Ages. Every cubic yard of slate represents the excavation of at least fifteen times the bulk of rock and about a third of the output is mined. With waste the total bulk of mined material to 1913 is about 47 million cubic yards.

Anyone walking over the chalk districts will notice saucer-shaped depressions scattered over the fields. Until recently it has been the custom to mine chalk for " marling " the land wherever the surface is covered by clay deposits. A shaft having been sunk through the overlying drift, a man descends and digs out the soft chalk round the shaft until a large bell-shaped chamber is hollowed

out. *In Buckinghamshire and Hertfordshire* these shafts are often as much as 50 feet deep. The arched roof of chalk stands well, and enough chalk to marl a moderate-sized field can be brought up from a single shaft. When the mine has yielded as much as it is safe to extract without danger to the miners, the shaft is filled up with soil shovelled in from round about it, thereby initiating the saucer-shaped depression. At other times timber is laid across the shaft near the top and soil laid over these, entirely hiding the hole for many years. In time percolating water weakens the shaft's sides and the depression increases. If the shaft has been simply covered over with timber and soil, the timber rots sooner or later and the ground falls in. In this way cattle have been suddenly engulfed without warning into holes of which the existence was unknown. The depression extends, as the shaft and probably the roof of the mine give way, until a hollow of round or oval shape, often 30 or 40 yards across and perhaps 10 or 20 feet deep, forms over the old bell-pit or dene-hole. Bell-pits are still occasionally made, but are now rare. The great number of depressions in the fields shows the extent to which marling was formerly carried on.

Chalk is by no means the only rock used for "marling" the land. Many of the clay formations contain a percentage of lime, usually in the form of fossils, and they have been extensively used for marling. One of the most widely spread geological formations in England is the Keuper Marl, and old marl-pits are scattered abundantly over its outcrop.

De la Beche stated that in Cornwall sea-sand and blown sand had been used for "marling" the land as far back as 1602. The lime is derived from the fragments of shells in the sand. As much as 4,000 horse-loads have been taken from Bude in a single day. De la Beche thought that about 200,000 cubic yards of sand was annually carted from the Cornish coast and spread over the land.

A Report on the lengths of the Underground Workings and Passages in some of the principal Collieries and Metalliferous Mines in England and Wales was presented, in 1881, to the House of Commons. It showed that in 294 mines there were 3,838 miles of workings passable by man, besides 2,245 miles passable also by horses and trams. The figures for disused workings must be much less than the original length of the passages, for many are blocked by falls of roof, filled by goaf, or flooded. Also

the 294 mines referred to form only a small part of the total number.

It is impossible even to guess at the total number of mines in England and Wales in use and abandoned. Some indication of the great number of disused shafts is given by the statement in the Mineral Statistics for 1854, that there were in South Staffordshire and Worcestershire, at that time, more than 500 collieries with at least 2,000 pits in full work.

The older workings must have been, on the whole, considerably nearer the surface than the present ones. Before James Watt invented his steam engine in 1769 a shaft 200 feet deep was uncommon. In the Report dated 1881, cited above, the average depth of the shaft in the case of 310 of the principal collieries and metal-mines was found to be 845·8 feet. Professor Hull, in 1890, estimated that the average depth at which coal was being worked at that time was 1,050 feet. Minerals are dug from increasingly greater depths as the mines become exhausted. Dr. W. Gibson thinks that at present the average depth at which coal is being got, in Britain, is about 1,500 feet. The underground passages therefore occur at different depths, and there are frequently several levels in a single colliery.

These underground workings are interesting from several points of view. They represent a mass of rock brought up to the surface from a considerable depth; they provide reservoirs and new channels for the circulation of underground water, and allow atmospheric gases to penetrate a long way below the surface of the earth, where they produce weathering similar to that at the surface; and they frequently cause subsidences after they have become derelict.

Allowing for all the waste, and also for the sandstone and fireclay obtained from the mines, it is probable the total amount brought to the surface in connexion with coal-mining, since the earliest times, is about one and a half times the bulk of the coal.

It is only possible to separate the output of mines from that of quarries in Mineral Statistics after 1895. Taking the nineteen years from 1895 to 1913, inclusive—that is to say, from the date of separation of the statistics until the last year before the war—we may compare the rocks and minerals obtained from mines with the quantities obtained from quarries. In the following table the second column gives the percentage of waste material estimated to have been

excavated in the extraction of the valuable mineral. The third column gives the total bulk excavated.

ROCKS AND MINERALS MINED DURING THE NINETEEN YEARS, 1895–1913

	Cubic Yards.	Percentage of Waste.	Volume Excavated in Cubic Yards.
Coal	3,829,935,396	50	5,744,903,094
Iron-stone	53,874,858	50	80,812,287
Gypsum	1,673,559	300	6,694,236
Rock-salt	19,560,799	25	24,450,998
Slate	1,223,559	1,400	18,358,830
Barium Compounds	175,473	100	350,946
Fluorspar	141,963	100	283,926
Zinc Ore	127,809	1,500	2,044,944
Tin Ore	25,005	10,000	2,525,505
Lead Ore	100,762	2,600	2,720,574
Copper Ore	37,298	1,000	372,980
Arsenical Pyrites	15,921	2,000	334,341
Iron Pyrites (not from collieries)	12,189	1,750	225,495
Gold Ore	104,055	—	104,055
Oil Shale	24,878,477	22	30,351,742

Comparing the total excavation from mines, 5,914,533,953 cubic yards, within the nineteen years with the estimate (p. 31) of the total from quarries during the same period, it is noticeable that the bulk mined is more than nine times the bulk quarried. This somewhat surprising fact is due to the enormous preponderance of the coal

output over that of all other minerals, for if coal were excluded the bulk of materials quarried would exceed that mined in the same period by nearly four times. In early days when minerals were obtained nearer the surface than now the proportion of mineral to quarried material may have been somewhat smaller than at present, but probably not appreciably, for the materials now mined could only have been obtained in quarries to a limited extent.

Excavations open to the sky are called quarries, in contradistinction to mines, which are excavations with a roof of rock.

Quarries existed in Britain even in Roman times, as witness London Wall, built of Kentish Rag, and Pevensey Wall, of sandstone from Eastbourne. In mediæval times local stone was generally used in important buildings such as castles or churches ; ordinary houses were of wood or of clay. Roads at that time were too primitive for transporting stone and it was carried to a distance by water-carriage. Thus, the stone for York Minster was brought down the Wharfe, Aire, and Ouse, while London was mainly supplied from Reigate and Chaldon, in Surrey, and Maidstone, in Kent. In the fourteenth century Kent also supplied stone for cannon balls, varying in weight up to 600 lb. The

earliest ornamental stones to be used for indoor decorations were Purbeck Marble, and alabaster from near Tutbury, in Staffordshire, and Chellaston, in Derbyshire. The waste from the alabaster was burnt for plaster of Paris.

Quarries were but small. Stone was obtainable with difficulty in the absence of modern explosives. A great deal was got for walls and filling ruts in the roads by collecting the loose boulders, which have been diminishing in number ever since Man began to settle down in fixed habitations. Roman remains also served as "quarries," and were pulled down for the building of new structures even up to quite recent times. With the enormously improved facilities for transport brought about by the introduction of railways, there has been a tendency to neglect local quarries and to obtain stone from a moderate number of large ones capable of supplying a large district, or even the whole country.

In addition to excavations worthy of the name of quarry, there are innumerable small pits (many now ponds) dug for various materials, such as chalk or marl for putting on the land; gravel, sand and clay for local use; and small quarries opened temporarily to provide stone for building a

house. There are also remains of old quarries now largely filled up and overgrown. Collectively these small excavations represent a very large bulk of rock. In order to form an idea of the amount of material they have yielded, the number and volume of all the pits and ponds within an area of 12 square miles was investigated and it was found that there were exactly 300 of these small excavations representing a total volume excavated of $2\frac{1}{3}$ million cubic yards. The area was a typical piece of British country, situated round Brewood, in Staffordshire, and on this average the total excavation in the 58,315 square miles covered by England and Wales would be 11,360 million cubic yards. This figure will be less than the truth, because many small quarries and pits have doubtless been so completely obliterated in the course of ages that they escape notice; nevertheless, the process of obliteration being a slow one, probably the proportion of pits now entirely lost sight of is not great. Quarries now being worked are not included, nor are mines, wells, road-cuttings, and other excavations, all of which should be added to find the full measure of artificial denudation. There has been probably much less excavation in Scotland than in England and Wales, as the former is comparatively

thinly populated, and we may therefore assume that the total excavation from old quarries and pits in Great Britain is about 15,000 million cubic yards.

The output from a quarry is only a part of the material excavated there, because there is always some waste. In the case of building-stones all the upper weathered and fissured stone is rejected, although some part of it may be used for road-metal or rough walling, etc. To the output for sandstone some 50 per cent. may be added to include waste stone, in addition to any overburden. In the case of limestone much stone unfit for building would be used for road-metal or burnt into lime, and therefore is not waste. In granite quarries the chippings are now not infrequently utilized for road-metal and artificial flagstones, while in the case of other igneous rocks it is chiefly for road-metal that they are being quarried. Gravel not infrequently contains clayey patches which are worthless. Almost always there is soil and sub-soil to be removed before any valuable materials can be obtained. This naturally forms a bigger proportion of the excavation in the shallower quarries.

We may now make a table for quarries similar to that given for mines.

	Output 1895–1913 in Cubic Yards.	Per cent. allowed for Waste.	Volume of Excavation in Cubic Yards.
Gravel	29,382,000	20	35,258,000
Clay (quarried) . . .	143,718,000	15	165,276,000
Sandstone (quarried). .	55,755,000	60	89,208,000
Igneous Rocks . . .	46,619,000	15	53,602,000
Limestone (other than chalk)	113,268,000	15	130,258,000
Chalk	43,135,000	15	49,605,000
Chert and Flint . . .	771,000	15	887,000
Gypsum (quarried) . .	436,000	400	2,180,000
Celestine	97,000	600	679,000
Slate (quarried) . . .	3,278,000	1,400	49,170,000
Ironstone (quarried) . .	30,370,000	90	57,703,000
Total . . .	—	—	633,826,000

In addition we must allow, from quarries not exceeding 20 feet deep, an output of sand, gravel and clay at least equal to that obtained from quarries over 20 feet deep, i.e., including waste, 200,534,000 cubic yards. Including other rocks we may estimate the total from shallow pits at half that from pits over 20 feet deep.

In 1895, the first year after the Act came into force, the number of quarries inspected in the British Isles was 8,150 ; and in 1913, the last year before the war, the number was 8,753. The difference is not great, the mean being 8,451.

Many shallow quarries that escape inspection have much larger outputs than some

of the inspected quarries, for gravel, clay, or limestone pits often cover several acres without exceeding 20 feet in depth.

An investigation leads to the conclusion that the average volume of a quarry is about 54,500 cubic yards, and the average "life" 9·6 years. This gives the bulk of rock excavated from existing quarries, and to it may be added 50 per cent. to allow for those under 20 feet deep. The result is a total of 489,439,000 cubic yards. Adding the total for old quarries (p. 30) we arrive at a total of 15,500 million cubic yards, in round numbers, as the bulk excavated from quarries in Great Britain since the earliest times. Spread uniformly over England and Wales this would form a layer 3·1 inches thick.

When constructing railways a skilful engineer so aligns them that the material excavated in cuttings and tunnels is just enough to make the embankments. As cuttings and tunnels are required in places that rise above the mean level of the ground and embankments in places that fall below, it follows that the material excavated is dumped at a lower level than that at which it occurred naturally, and therefore the final effect is to lower the general level of the country. The bulk of material excavated

is lowered by an amount equal to the height above rail-level of the centre of gravity of the excavated mass, added to the depth of the centre of gravity of the embankment below rail-level.

Rock excavated is of course broken into fragments in the extraction, and therefore in the embankments will occupy more space than in its original condition. The sides of the cuttings, tunnels, and embankments offer new surfaces to natural agents of denudation.

The total length of railways in the British Isles, at the end of 1909, was 23,272 miles.

The formation of the Great Central Railway gave an opportunity for estimating the quantity of materials removed or used up when a railway is built. Messrs. F. W. Bidder and F. D. Fox have given the quantities for the northern and southern sections of the railway respectively. The railway is sufficiently long to pass through varied country and to contain all the "works," as they are called (tunnels, bridges, etc.), usually found on a railway. It may be used therefore to supply the data of an average British railway; and by multiplying the total length of railways in the country by the quantities per mile length, as obtained from the engineers' figures, we find the approximate quantities of materials

that have been dug out in making British railways. On these figures Man had excavated on British railways, up to 1909, 3,030 million cubic yards, which is approximately equal to excavating 1,000 square miles to the depth of a yard.

The earliest British canal was made at Exeter, in 1563. The first canal to be made across country, independently of the course of the existing streams, was the Duke of Bridgewater's Canal from Worsley to Manchester, in 1761. By the end of the eighteenth century most of the British canals had been made, and the system was completed by 1830, with the exception of the Manchester Ship Canal and a few short cuts or arms. Since then the mileage has diminished, for several canals have been converted into railways, or become derelict. In 1909 there were in England and Wales 1,927 miles of canals. It has been pointed out by L. F. Vernon-Harcourt that "Owing to the necessity of constructing canals for navigation in a series of level reaches, and the excavation of a trench for the waterway, the earthwork required for making a canal is considerably greater than for a railway of similar length, especially in the case of ship-canals, where it is expedient to introduce as few locks as possible." The

material excavated is usually thrown up as banks alongside the canal.

It can be shown that the materials excavated from canals in England and Wales exceed 200 million cubic yards, without including the Manchester Ship Canal. This canal deserves separate mention on account of its dimensions. At Runcorn, the cutting is not less than 70 feet deep, and for the next 6 miles is from 35 to 60 feet in depth. The minimum bottom width is 120 feet, and the length is 35½ miles. The total amount excavated was 53½ million cubic yards, of which 2 million were sandstone rock and the remainder loose material. Part of the rock and earth excavated was utilized to fill in the river-channels where these had been diverted into the canal; but the greater part was deposited in spoil heaps and railway embankments.

Road-cuttings are in part the result of attrition by traffic, but to a great extent are due to direct excavation. Some instances of attrition are given in the next chapter; here we are concerned with the amount excavated.

Near towns situated in hilly regions it is usual to find roads cut as notches into steep hillsides. Often, too, houses are built on ledges dug out of solid rock. A few amongst many instances are Sheffield, Barmouth,

and Todmorden, where in each case the rock is usually a massive grit. In such places road-excavation reaches impressive proportions, and it is difficult to strike an average between such cases and the plains, where road-cuttings are practically absent. The fact that it is usually hard rocks that need to be cut into adds of course to the geological importance of road-cuttings, since such rocks are the most resistant to natural erosion.

Some road-cuttings represent an amount of denudation comparable with that produced by an extensive railway-cutting. An instance is the Derwent gorge at Matlock which is so narrow that it had to be enlarged by blasting to make room for the turnpike road.

An estimate of the bulk of rock and soil excavated in roads is even more difficult than in the case of quarrying. Examination of a definite area in Hertfordshire leads to an estimate of 8,500 cubic yards per square mile for England and Wales, and half that for Scotland. This means that road-cuttings in Great Britain represent the excavation of 624 million cubic yards, in round figures.

In many cases large quantities of rock have been excavated during the making of docks, and 100 million cubic yards seems

a moderate allowance from this source for Great Britain.

A very large amount of rock and soil must be excavated in digging out the foundations of buildings and in various street excavations, whether to lay drains, gas, or water pipes, telephone or telegraph wires. Until recent years the excavations have usually been shallow, and not, as a rule, carried below the subsoil. Of late years more lofty buildings are being built and foundations are consequently being dug more deeply; also the large cities are excavating solid rock in their main drainage schemes. The case of London is referred to on page 98.

We may now add up the various kinds of excavation discussed in the preceding pages.

TOTAL EXCAVATION IN GREAT BRITAIN TO END OF 1913

	Cubic Yards.
Mines	19,692,000,000
Quarries and Pits	15,500,000,000
Railways	3,030,456,000
The Manchester Ship Canal	53,500,000
Other Canals	200,000,000
Road-cuttings, about	624,000,000
Docks and Harbours, say	100,000,000
Foundations of Buildings and Street Excavations, say	500,000,000
About	39,710,000,000

This total, while it does not pretend to a *high* degree of accuracy, is nevertheless probably sufficiently accurate to give a just idea of the amount of excavation in this country. We shall discuss its significance in the final chapter.

CHAPTER III

THE DESTRUCTION OF ROCKS BY ATTRITION

ONE of the greatest changes in the earth's surface wrought by Man is due to the way in which he has covered many square miles of it with pavements and buildings. These act as armour, protecting the ground against the ordinary agents of denudation. Although such surfaces are themselves exposed to atmospheric agents, they have been expressly chosen for their high resistance to denudation, and moreover, should they yield to attack, they are promptly repaired and the ground underneath remains unaltered. On the other hand, pavements are subject to a special kind of denudation, that of constant attrition.

The amount of denudation due to attrition by traffic is very great. It may be estimated by the quantity of materials required in a given period to keep the roads in good condition, or by observations on the "life" of roads of different kinds. Some roads require re-making more frequently than others, although the worn materials taken up may be

used again in a less important place. But, if a suitable area and period are considered, the quantities of new materials used to keep the roads in repair will be the measure of the quantities that have been ground to powder and have found their way either into the drains and thence into the rivers, or else have been blown in the form of dust on to the land and become part of the soil.

The alternative method of estimating the amount of denudation is to find the output of all the quarries engaged in producing road-metal, setts, paving-stones, and "hoggin," corrections being made for artificial materials such as slag, bricks, and tiles, and also wood, which are now being used in large quantities. These artificial materials (except wood) have themselves come from quarries, for they are the ultimate products of coal, ironstone, clay, limestone, and so forth. These substances, however, are for the most part soft, when dug out of the earth, and may be considered separately from the hard rocks quarried for covering roads.

An attempt to estimate the bulk of rock excavated in Great Britain for pavements, and worn away, since the earliest times, meets with great difficulties. The amount used per annum has increased very rapidly, partly because of the increase in population

and traffic, and partly on account of the improvement of roads.

Before the Roman invasion there were scarcely any made roads in Britain at all, only tracks beaten by the feet of man and animals. In the valleys the forests and bogs were wellnigh impenetrable. One forest stretched from the Thames to the Fenland, and is now reduced to Epping Forest; another spread down from West Yorkshire to Nottingham. The Fenlands covered twice the present area and were at that time impenetrable bogs. These conditions persisted to a great extent through the Middle Ages, although in certain counties the average of arable land was greater then than now. Extreme cases are Somerset, where in 1086 there were 577,000 acres of arable land against 178,967 acres in 1907, and Gloucestershire, where there were 589,000 against 238,456 acres in 1907. Between the eleventh and sixteenth centuries much of the arable land was laid down to grass, but a great deal of the country was in a wild and uncultivated state. Woods sometimes grew right up to the walls of towns. An unbroken series of woods and fens stretched right across England from Lincoln to the Mersey and from the Mersey to the Solway and Tweed.

Before the country was settled natural

ways of communication were offered by the grasslands, and the chief of these were the chalk downs. A track, which afterwards became the Pilgrim's Way, was beaten out by bare feet along the southern outcrop of the chalk, and, similarly, the Icknield Way was formed along the top of the Chiltern Hills. "Ridgeway" roads, however, are not confined to the chalk areas, but are found in many parts of the country. In the Brendon Hills, Somerset, for example, a road extends along the top of the ridge in a nearly straight line for many miles and is associated with numerous tumuli, indicating its great antiquity.

The Romans were the first European nation to attain an advanced stage in highway construction. In the prosperous days of the Empire, twenty-nine military roads are said to have radiated from Rome, and these with their branches had a total length of more than 50,000 miles. The roads were from 8 to 16 feet wide, and the paving materials were 3 or more feet in thickness.

The materials available for road-making naturally varied locally. The stones used were most probably boulders or blocks gathered from the surface, or obtained by shallow digging, as a rule, but occasionally paving-stones were quarried.

With the passing of the Roman power the roads were neglected. The Angles and Saxons preferred to build their villages on streams, away from the roads. New tracks were trodden out between the villages, but there was practically no traffic along the old roads, and these became derelict.

From the time of the Roman evacuation of Britain practically no road-making was done in the country until the middle of the eighteenth century. The roads, as we have seen, were originally mere footpaths or horse-tracks, and the few wheeled carriages were of rude construction, for which roads were wholly unadapted. They were tortuous, any obstacle turning the traveller aside. Many went over hills to avoid marshes, others deviated to communicate with fords of rivers, now passable by bridges. Inland commerce was carried on chiefly by pack-horses. In Norman and early Plantagenet times there was a considerable amount of travelling. Nobles migrated from one manor to another, the policy of the Norman kings being to split up their vassals' estates into scattered pieces to prevent rebellion. However, estates presently became consolidated and the nobles no longer travelled much, while the Wars of the Roses also brought about great changes. The roads

became deserted and were allowed to decay.

After a long interval of time the roads gradually became passable for the primitive carriages and were maintained by local taxes on parishes until turnpikes were introduced by law. Several of these were installed before 1765 and subsequently they became general. It was a long time, however, before a good system of road-making was established. Old horse-tracks were generally followed, with a few deviations, and deep ruts filled with stones or any material at hand. These were thrown on in an irregular mass and roughly spread to make them passable; the best of them would now be intolerable. Engineers, except in the case of exceptional difficulties, such as when it was necessary to bridge a wide river, thought roads beneath their notice; and it was considered singular when, in 1768, Smeaton condescended to make a road between Markham and Newark.

As an illustration of the condition of the roads it may be mentioned that in the reign of Edward III the footway at the entrance to Temple Bar was interrupted by thickets and bushes, and farther west faggots were thrown into the ruts in King's Street, Westminster, when the king went to Parliament.

Between 1331 and 1380 Parliament three times adjourned because the state of the roads kept many members from attending.

The first Act for paving and improving the City of London was passed in 1532. Before the turnpike was introduced, the metropolis and other large towns were paved with rounded boulders, or large irregular pebbles, imported from the seacoast. Boulder pavements were succeeded by pavements made of blocks of stone so irregular in shape that even the surfaces did not fit. The stones were but lightly hammer-dressed. This method of paving was in existence up to about 1830, when, as the result of Telford's work, modern paving was adopted, and by about 1850 the old style had practically died out.

In Elizabeth's reign the great western road was so bad that in winter travellers waded through deep mud at Knightsbridge. Farther from London matters were worse. Roads were mostly tracks over heaths and commons, furrowed with ruts like ploughed fields. All the mending done was to throw large stones into the bigger ruts to fill them up. The land being unenclosed, it was usual, when the road got very bad, to make a new track alongside the old one. Beacons were erected to warn travellers of the more

dangerous quagmires, and guides were necessary to point out the safest fords, in the absence of bridges.

So little was known of the more distant parts of England that in 1607 we find Camden describing Lancashire as that part of the country "lying beyond the mountains towards the Western Ocean." In country places stores were laid in for the winter as if for a siege. Most of the sheep and cattle were killed and salted down at Martinmas, while stockfish and baconed eggs were provided for Lent; for during six months the roads were closed.

Before the formation of the Great North Road it was one of the principal bridle-paths from London to the northern parts of England; but it was so narrow as barely to afford passage for more than a single horseman, and so deep that the rider's head was beneath the level of the ground on either side.

During the Civil War 800 horse were taken prisoners in Buckinghamshire while sticking in the mud. When rain fell, travellers all came to a standstill until the road dried again. In 1645 it took two days to travel from London to Chertsey. One of the first coaches in England was used by Queen Elizabeth; but for a long time roads

were barely practicable for wheeled vehicles of the rudest sort. Stage-coaches were introduced about the middle of the seventeenth century, and probably between London and Dover, as this was one of the best roads in the country. To show the extent of travelling about this time, it is stated that between London and the three principal towns of York, Chester, and Exeter, not fewer than 1,872 persons travel by stage-coach in the year. In 1700 York was a week distant from London; Tunbridge Wells, Salisbury, and Oxford were each two days; Dover three days; Exeter five days. As late as 1763 it was a fortnight's journey from London to Edinburgh, the coach starting once a month.

Even as late as 1809 roads were very bad, but the General Views of the Agriculture of the Counties of Great Britain, a series of volumes published about the beginning of the nineteenth century, show that the coming of turnpikes and mail-coaches had caused a great improvement in many countries. In general, however, the turnpikes were very bad. They were covered by many inches of mire, and the sludge was thrown all over a horseman, even into his eyes, on meeting horses. The road from Tyburn (Marble Arch) to Uxbridge had the most traffic in

Middlesex and perhaps in the country, yet, in the winter of 1797–8, there was only one possible track on the road, and this was less than 6 feet wide and 8 inches deep in fluid sludge.

Scotland as a whole was far behind England. In 1803 a writer in the *Farmer's Magazine* sums up his account of the country thus: "Except in a few instances it was little better than a barren waste." The plough had not reached the Highlands; the people used the caschrom, or "crooked foot," which was pushed into the soil to turn it over. There was no road of any kind west of the Great Glen, a state of affairs that lasted until Telford began to make his roads, bridges, harbours, and canals in 1804. With the introduction of Telford's system of road-making in 1803 and Macadam's in 1816, modern road-making, in England, may be said to have begun.

We may divide the history of British roads into four periods: (1) before the Roman roads were made; (2) the period of Roman occupation; (3) from the end of the Roman occupation to early in the nineteenth century, when modern road-making was introduced; (4) from the introduction of modern roads to the present day, approximately a century.

The amount of erosion depends on the

time during which the agent acts and on the rate at which it works; hence the necessity for the above divisions, which represent the different periods during which the rate of denudation had different values.

In the first period, before the making of the Roman roads, Man's denuding action was similar to that of other animals. Just as a herd of buffaloes will beat out with hoofs a path to the watering-place, so primitive Man beat out with his feet such roads as the Icknield Way. It is not unlikely that he sometimes threw pieces of rock into swampy places, or into streams, to make stepping-stones, and so performed a primitive engineering feat; but this is not a purely human action, for greater engineering feats are performed by beavers when they dam a stream and make a considerable lake. At this time the population was probably very small, though we have no figures. The human denudation during this period is practically negligible; the limited population did scarcely any travelling from place to place, and used neither vehicles nor iron-shod horses, and such wearing away as was actually effected was performed by Man in his animal rather than in his human character.

In the second period, that of the Roman

occupation, distinctly human erosion was effected. Definite strips, the metalled roads, were undergoing abrasion during a period of about 500 years.

The rate at which the roads were abraded is unfortunately not known; it is only in recent times that we have any data to work on.

The Romans used metal studs in their shoes and shod their horses, thereby introducing a new element of abrasion.

In the third period, after the Roman occupation, their roads were partly allowed to wear out without repairing, partly left to become overgrown, partly pulled up in order that the stones they contained might be used for building. Conditions were much as in the pre-Roman period except that (1) the population slowly increased on the whole, though with periods of decrease; (2) traffic, at first almost non-existent, increased as the times became more settled; (3) vehicles began to be used late in the period and introduced a new abrasive element. Shoeing of horses having been introduced by the Romans probably continued throughout the period, and it was also customary to shoe oxen when they were used to do the work now performed by horses.

For this period also we lack data; but it is safe to say that the denudation effected directly by traffic was trivial compared to that performed at the present day. One important difference between the third and fourth periods should be noted. Until the modern methods of Telford and Macadam had taken root, such mending of roads as was done at all consisted in filling up holes with loose stones, and later on cobbles were brought inland from the seacoast, to make the first town pavements. Two results must have followed: the country became less stony owing to the picking off of loose fragments during so many centuries, and secondly, the removal of stones from the coast would assist coastal erosion by the sea (p. 159).

It is in the fourth period, which is still existing, that the bulk of human erosion has been performed. Probably some 99 per cent. of the total rock removed by direct abrasion alone has been effected within the last century.

About 1830 London began to be paved with granite setts, of different sizes according to the class of streets, and below the setts a foundation of broken stones, one foot thick, was placed. Macadam was used in some streets for light traffic.

By 1850, the change to a modern style of paving had been completed. In Fleet Street a pavement lasted for fourteen years, after which the setts were used in secondary streets for twenty-nine years. The average double life of a three-inch sett of granite was about thirty to forty years at this period.

In Manchester the early pavements were boulders from the coasts of Wales, Westmorland and Cumberland, as also in the case of Liverpool. Boulders ceased to be imported into the city in 1840; and although considerable areas of boulder-pavements remained in 1876, these were replaced by granite-setts when roads needed repair.

For paving-stones, Yorkshire flags, 3 inches thick, were used, and lasted eighteen years in the main streets and then another fifteen to twenty years in side streets, giving a total life of about thirty-six years (another statement gives nineteen years).

Towns have continued to grow very considerably in size, and traffic has increased still more rapidly. On the other hand, improvements have been made in pavements, and the use of asphalt and wood has tended to diminish the quantity of stone used, while rubber tyres have greatly reduced abrasion. The pneumatic tyre has only been in use for about forty years on

bicycles, and motor traffic may be said to have commenced in 1896, when an Act allowed the speed to be increased from four to twelve miles an hour. The coming of pneumatic tyres necessitated the improvement of roads.

Some observations were made by the author in order to estimate the fraction of the country covered by pavements. The results show that, in two rural districts examined, almost exactly $\frac{1}{2}$ per cent. of the total area is paved. If we consider also towns we find that the fraction of England and Wales which is subject to attrition from the feet of Man and his domestic animals and the wheels of his vehicles is approximately 1 per cent. An increasing proportion of the road surface, however, is being covered by wood or asphalt pavements, the former derived from trees, the latter from mineral pitch or from coal and therefore dug out of the earth.

Estimates of the quantities of materials worn out by attrition on roads are unsatisfactory. They very greatly and also refer to markedly different periods and conditions of traffic, so that it does not seem possible as yet to arrive at accurate figures. The mean of several investigations may be taken as 400 cubic yards per mile per annum

denuded from roads throughout Great Britain, leaving out of consideration the footpaths at the side of the roads and private walks in gardens, etc.

Taking Mr. J. W. Smith's figures of 175,225 miles as the total length of paved roads in Great Britain in 1908–9 and multiplying this by 400, the number of cubic yards annually required, on the average, per mile to keep the roads in repair, we find that approximately 70 million cubic yards of stone are annually used up in Great Britain, in addition to the materials worn away on footpaths. Another method of calculation, however, gives discordant results (p. 57).

It is important to remember that although roads are denuded they are not allowed to be worn into depressions, as would happen to a natural surface. No sooner is a part of the road-covering destroyed than more material is brought from a quarry to replace it. Hence, although the roads are the places where rock destruction is effected, the results of denudation are seen in quarries in, it may be, a distant part of the country or even of another country. The natural surface under the pavement is "armour plated," as it were, against denuding agents. As the part of England and Wales covered by pavements is 1 per cent. of the total area and

another part is protected by buildings, it is clear that a considerable section of the country is protected from denuding agents.

Footpaths are usually paved with flagstones in towns, and the best-known stones are those from Yorkshire and Caithness. At present much of the flagstone used, probably more than half of the whole, is artificial, consisting either of chippings of granite, etc., set in Portland cement, and often treated with soluble glass; or clinker from refuse-destroyers. In some cases they are made of iron-slag, cast into slabs. A variety of substitutes for flagstones are in use, notably bricks. In many districts, for example in the Black Country of South Staffordshire, bricked or tiled footpaths are common. They are, however, taking the country as a whole, distinctly subordinate to flagstones. In villages and such country roads as possess footpaths they are usually covered by gravel, with a kerb and channel, although these latter are not infrequently absent. The extensive use of artificial products such as concrete, brick, and clinker, greatly diminishes the quantity of natural stone required. This means that quarries of solid stone tend to be replaced, to some extent, by clay-pits and gravel-pits, and also that the waste products of towns and quarries,

instead of accumulating as of yore, are turned into paving materials and eventually disappear into dust.

In order to check the quantities of stone used up on the roads we may try to find the amount of stone quarried for road-making. We are mainly dependent on the Home Office Statistics for the figures, and great difficulties arise in using them. For one thing the form of the statistics has been repeatedly changed; for another some of the stone was used for buildings, although most was used for road-making. Of late years a large and increasing quantity of stone for roads has been imported from abroad, and has prevented an equivalent amount of quarrying being done in Britain. The further fact that the statistics do not include quarries under 20 feet deep is less important in this case than in that of clay, sand, and gravel, because quarries in igneous rocks are usually of considerable size and depth. Nevertheless, there are many small quarries opened for local use which escape the statistician. Some additional figures are obtainable from the "Census of Production" for 1907, issued by the Board of Trade, but these do not agree very well with those issued by the Home Office. Taking average figures for

the densities of stone, the output of igneous rocks in 1913 (on Home Office figures) would have a bulk of about 3,200,000 cubic yards; the sandstone of 2,404,000; the limestone used for road-metal about 557,000 cubic yards. Even if the whole of the igneous rocks and sandstone was used for road-metal, which is not the case, the total amount used in 1913 would be not much more than 6 million cubic yards, as against 70 millions required under the calculation from wear and tear of roads given above (p. 54). Even if we assume that a considerable quantity of gravel, slag, flints, imported stone, and other materials was used, it is clear that these two methods of calculation give discordant results.

Of the igneous rocks an unknown proportion, chiefly of granite, is used as building-stone or for monumental work, and the rest mainly for road-making. In the case of sandstone the bulk would be used for building-stone, with smaller quantities for monumental work, flagstones, ganister (for silica-bricks), etc. Many "granite" setts are made out of millstone-grit, and it is a question under which type of rock they have been entered.

The destination of the limestone is better known. Leaving chalk out of consideration,

the Census of Production divided the 10,993,000 tons of limestone got in 1907 into building-stone 350,000 tons; road-metal 1,110,000 tons; burnt for lime 2,740,000 tons; while the use of the rest is not specified.

Stone burnt for lime is completely destroyed as rock and becomes part of mortar or cement, or is placed on the land, where it combines with acids in the air or soil. The stone used for buildings has a variable life. We are all familiar with the weathered aspect of buildings, especially in towns. Limestone used in country places may last for many centuries, as witness our old churches; but in towns the same stone may perish in a few generations. Sandstones, unless they have a calcareous cement, last longer than limestones, but suffer by the action of frost and rain as well as by direct mechanical destruction. Igneous rocks resist weather better on the whole. They also are affected chemically by the town atmosphere, which attacks the felspar constituent and so disintegrates the stone. Since it is man who dug the stones from places where they were protected from the weather and exposed them to destructive agents, the weathering may be ascribed to human agency.

Buildings are usually pulled down long before the stones of which they are composed are destroyed. A building the lease of which has fallen in, or which has become disused, is generally pulled down. The sound materials may be used in other buildings, but there is always a lot of stone not worth using again, or which has been accidentally broken. Such damaged stones are generally used for "hard-core" for road-foundations, made into concrete, or broken up for road-metal. For a while the stones may lie about on waste land, and some may be incorporated with "made-ground"; but sooner or later building-stone, in general, becomes road-metal, and so also does much monumental stone. Thus the greater part of the output of the quarries is eventually reduced to powder, if not totally destroyed.

It is clear that an unknown but very large proportion of the rock that had been quarried in Britain (estimated on page 32 at 15,500,000,000 cubic yards) has been, or is being, ground to powder on the roads. But this is not all. Ancient slag-heaps are now being "quarried" for slag, which, mixed with tar, is in great demand. Slag, although artificial, is made from mineral substances which were quarried or mined; and therefore the product of mines, and notably coal,

in the form of ash combined in the slag and coal-tar, as well as the gangue of ores, is used for road-metal.

The more incoherent materials dug out of the earth, such as clay, sand, and gravel, are also used in part on roads; the clay in the form of new or broken bricks, the sand and gravel for paths and as a surface-dressing.

Important sources of road-metal that must not be overlooked are broken-up boulders and stones picked off the fields. In the areas covered by Bunter Pebble Beds, or the Drift derived from them, the pebbles are for the most part of hard quartzite and are put on the by-roads. Similar hard stones are also collected over the outcrops of other conglomeratic, sandstone, and igneous rocks. In the Chalk districts there are extensive areas covered by Clay-with-flints, which is a *remanié* deposit of clay or loam containing numerous weathered flints. The fields are often extremely stony, and in many cases the flints are picked off every fourth year and sold for road-metal. In one instance the quantity picked was at the rate of 9 cubic yards per 4 acres annually.

Over a very large part of Britain the Pleistocene ice-sheet has left boulders, called erratics, and as these interfere with agri-

cultural operations, those sufficiently near the surface to impede the plough are dug up. This operation is carried to a greater depth than might be expected, for after drought or improved drainage the soil shrinks, and boulders catch the plough that were formerly out of reach. The removal of tilth by wind and rain also lowers the surface-level and brings new stones within range of the plough. Many of the boulders are built into walls round the fields; others have been placed outside gateways for use, when horse-riding was universal, as mounting-blocks. In some districts the erratics, which are for the most part of hard rocks, have been nearly all broken up for road-metal.

At this point mention may be made of the "hollow ways" belonging to various periods, but mostly formed before modern pavements were invented. The remains of one may be seen at High Wycombe, near and parallel to the road to Amersham. The greater part of it has been filled up and built over; but parts can still be seen as gullies about 12 feet deep. This road may be an ancient British way, for the Amersham road is itself Roman and the hollow way appears to be older. An interesting case is to be seen at Digswell, north of Hatfield, where a

deep and overgrown gully represents the former Great North Road. The gully is about 15 feet deep by 550 yards long, and part has been filled in and built over. Although this hollow way is quite like the one at High Wycombe and to all appearance as ancient, it has only been derelict for about sixty years, when it was replaced by the present road. These old roads are sunk in chalk, which is readily worn away.

Sidney and Beatrice Webb in *The King's Highway* remark that about 1600 the growth of London and other towns caused a great increase in road traffic. Goods were usually carried on pack-horses, and this led to the formation of causeways paved with flags or boulders. Parts of these causeways may still be seen, e.g. on the Yorkshire moors between Todmorden and Huddersfield. They were about 2 or 2½ feet wide, and there is usually a channel down the centre worn out by the horses' hoofs. In 1739 people riding from Glasgow to London travelled on a narrow causeway with an unmade soft road on either side until they came to Grantham, within 110 miles of London. The growth of London affected traffic all over the country. It is estimated that about the middle of the eighteenth century some 40,000 Highland cattle annually tramped to Nor-

folk and then, after fattening, on to London. Some 30,000 head of cattle were brought from Wales. In all about 100,000 cattle and 750,000 sheep were annually driven to Smithfield during the third quarter of the eighteenth century. Pigs, geese, and turkeys (150,000 turkeys annually passed Stratford Bridge), in addition, all helped to keep the roads in a muddy condition.

After the introduction of toll-gates many new (" drift ") roads were formed to enable the droves of cattle to reach London and other towns without using the toll-roads, and this not only to avoid paying toll, but because unmetalled ways were less tiring to unshod animals than the high-roads. Many of the crooked lanes, so characteristic of England, originated in this manner, and some of them have become more or less hollowed out by the traffic. This is particularly noticeable near a ford, but it is frequently difficult to discover how much of the cutting has been made by an engineer and how much is due to attrition.

Although the abrasion of rocks by man is most marked on roads, it occurs under other conditions also. In the process of shaping stones for the builder much dust is produced, as also in all abrasive processes, such as the polishing of glass by sharp sand,

which is worn round in the operation. Millstones and grindstones of sandstone or emery offer other instances of attrition. However, probably the most striking instances, after the abrasion of roads, are the cases where rocks are powdered to extract minerals disseminated through them. In Britain the most marked cases are probably associated with lead, zinc, and tin mines, where the "slimes," as they are called, form large dumps.

In other cases a mineral is used in a powdered form, as is the case of gypsum. "Terra alba," which is merely gypsum ground to an impalpable powder for use in paper, paint, and other manufactures, represents probably more than half the output of gypsum. Barytes, china-clay, talc, and some other minerals are similarly dealt with. Whiting (powdered chalk) is prepared in large quantities, and the whiting-pits at Grays, Essex, are comparable in area with the great Penrhyn slate quarry. Flints also are reduced to impalpable powder for use in porcelain.

Excellent illustrations of the pulverizing of rocks are found in South Africa. From the gold-mines of the Rand, up to 1929, there had been extracted 700 million tons of hard conglomerate, the Banket. The

pebbles of this conglomerate are of quartz, yet the whole mass, pebbles and matrix alike, have been ground to fine powder to extract the gold. The silt is dumped into mounds and when dry is blown by the winds and scattered widely over the surrounding country, though much collects into dunes. We may estimate that a ton of the Banket produces a cubic yard of dust, and so the total bulk of the dust made up to 1929 will be about 700 million cubic yards.

The diamonds of South Africa are found in the necks of ancient volcanoes. The material filling the necks is called "blue ground," and after extraction it was formerly spread out to undergo weathering, a process aided by working it with harrows. When reduced to powder it is washed to extract the diamonds. Nearly 100 million tons of rock has been mined and powdered from the Premier Diamond Mine alone, since its discovery in 1903.

We cannot give any close estimate of the quantity of rock destroyed in Britain by attrition. It cannot well be less than 10 million cubic yards annually, and may be considerably more.

A large proportion of the rocks and minerals excavated is totally destroyed. By attrition they are ground to fine powder,

but the dust retains at least its chemical composition. When limestone is burnt in the kiln to make lime; when cement-stones or mixed clay and limestone are burnt into Portland cement; when gypsum is burnt to make plaster of Paris; when clay is made into bricks, tiles, stoneware, or other article; when coal is burnt alone or with metallic ores; even the chemical composition of the rock is altered and new substances are produced. An estimate of the quantities of these artificial rocks will be attempted later on in Chapter VI.

CHAPTER IV

SUBSIDENCE

As early as the fifteenth century instances of surface damage caused by mining had come before British law-courts, and there are numerous records of such cases; but the subject of interest has generally been the monetary value of the damage done. This depends on the accident of the subsidence occurring below some important structure such as a reservoir, canal, or railway, where, although the actual subsidence may be trifling, the damage may be very great compared with that under open country, where it is scarcely noticeable. From the geological standpoint, however, the monetary value of the damage done does not matter; it is the extent of subsidence, the effects on the strata, the disturbance of drainage and so forth that are the important considerations.

The study of subsidence due to mining is still in an unsatisfactory condition. Although a good deal has been written on the

subject it has to be sought in numerous publications and in many languages. The work done has been usefully summarized by Messrs. L. E. Young and H. H. Stoek of Illinois. They show that theories to explain subsidence vary with the nationality of the investigator, and that very different results have been arrived at in different countries.

Much discussion has arisen as to whether deep mines do or do not cause surface subsidence. On the one hand it has been supposed that the shattering of the unsupported rocks above the mine causes them to fall in, and in doing so, since broken rock occupies more space than unbroken rock, fill the void; on the other, that the entire mass of material above the immediate roof of the coal may settle without increase of volume and so cause subsidence.

An observation by Graff, that drainage does not cause any change of volume of sand, has a bearing upon the subsidences in London supposed to be caused by unwatering the gravel foundations of buildings.

T. A. O'Donahue pointed out that the subsidence caused by the removal of a 6-foot coal-seam is more than twice that produced by the removal of a 3-foot seam, because in the former case little material is thrown into the gob (the abandoned excavation), whereas

in the case of a thin seam it is necessary to mine also some rock above and below, and this waste serves for packing.

Probably the most valuable researches on subsidence are those of Monsieur Fayol, whose work explains much that was contradictory in the theories of other writers. Professor Galloway has given an excellent account of the investigations carried out by Fayol, at Commentry in France, on the distance and direction in which the effects of subsidence due to extraction of coal extend. Subsidence is felt for a certain distance above the excavation, but may not extend up to the surface. The area affected forms an ellipsoidal block cut off below by the excavation. If this lies horizontally the ellipsoid is symmetrical about a vertical plane through the middle of the excavation, but if, as is usually the case, the coal-seam was inclined, then the ellipsoid is unsymmetrical.

Subsidence is partly prevented by careful packing of the waste stone into the excavations. Broken rock is usually rather more than twice as bulky as the solid rock, and under pressure it is sure to contract. We may say that ordinary materials, such as shale and sandstone, after having undergone an increase of volume of 60 per cent., undergo a shrinkage of about 30 per cent. in

mines between 100 and 300 metres deep (328 to 984 feet), leaving them with a volume about 12 per cent. greater than that of the compact rock from which they were obtained. Moreover, the materials stowed are very unequally compressed; in some places they are practically loose, in others crushed and solidified by the pressure. The action of water is also important: in its presence pressure is no longer necessary to fill up the voids and reduce the "stowing" to a high degree of density.

The hollow produced at the surface of the ground by subsidence is usually concave in the centre and convex on its edges. The convex part has been stretched and cracks are produced which close as the subsidence extends, and are succeeded by others on the new convex edge.

The usual method of reducing subsidence is to pack all waste material into the excavation, and such waste is often spoken of as "gob." W. Griffith has patented a method of preventing subsidence by blasting the floor and roof of the worked-out mine. His idea is to utilize the increased bulk of broken rock by blasting sufficient of the floor and roof to fill the void.

A very important method of avoiding subsidence is to fill the mine-workings with fine

material carried by water through pipes. The method is said to have been first used in 1884 to extinguish a fire near Shamokin, Pennsylvania. In 1914, there were twenty-seven collieries in Silesia using the method. In that country it is usual to dig sand with steam shovels and transport it by railway to the mines. In the Saarbrucken district hydraulic filling is used in iron- and potash-mines as well as in coal-mines.

In Britain the only moderately extensive installations at work are at Motherwell, but there are a few small installations besides. The method has been used on a small scale at the Crowgarth iron-mine, in Cumberland.

At Scranton, Pennsylvania, it was proposed to build a new railway depot over old coal-workings. A borehole was made and a six-inch pipe put down through which 9,400 cubic yards of sand were flushed. In the same town ashes were flushed down into the old workings under a new power-house, and in 1916 the Electric Company was sinking a shaft down which their furnace-ashes are to be dumped into the old workings, to avoid the expense of haulage.

Pneumatic filling has been successfully employed at several mines in the Lake Superior copper district. In addition to the waste material discarded in the stopes,

sands from the stamps and tailings from the concentration plant are brought a distance of eighteen miles and discharged by compressed air into the worked-out stopes.

In some cases piers of masonry or of concrete are used in mines. In the Tilly Foster Mines no less than 20,189 cubic yards of masonry were built underground.

In South Africa there has been subsidence over the Rand gold-mines where the depth of the workings has been not greater than 710 feet below the surface. It is believed that workings below 1,000 feet in the Rand will not cause any subsidence.

In Pennsylvania the city of Scranton is estimated to have had 177 million tons of coal excavated from beneath it during the seventy-five years of active mining. This quantity represents a volume of 198 million cubic yards, an amount equal to the total amount of rock excavated in making the Panama Canal. Under a part of the city there are eleven important beds of coal having an average aggregate thickness of 58 feet.

Instances of subsidence due to mining are very numerous in Great Britain, but it is difficult to estimate the extent of the depression in a particular case. Buildings, railways, bridges, tunnels, canals, reservoirs, roads, water- and gas-mains all show damage.

Subsidence may commence immediately after the removal of the mineral, or not until some months have elapsed, and it may continue from two to thirty years, the subsidence being slower when the mining is deep.

The effect of subsidence will, as a rule, be greatest towards the middle of a coal-field that is basin-shaped, with the newest measures towards the centre, where in consequence a number of workable seams will usually be found one above another. In this country as many as twelve coal-seams have been worked from a single shaft, although, owing to the high dip in the particular case referred to, all the seams are not sunk through in the shaft, but are intersected by a main level.

Subsidence will usually be considerable where there are several workable seams over one another, not only because of the total thickness of coal removed being greater than for a single seam, but also on account of the repeated disturbance of the overburden when mining at different levels.

According to Mr. W. D. Lloyd, the theory that there is a harmless depth has not been well received in Britain. He says that it is generally recognized that, except where the area undermined is comparatively small,

the surface must ultimately be disturbed, although the subsidence may be so gradual and uniform that it is not noticeable. He quoted Mr. J. A. MacDonald's statement that coal had been worked for at least a century and a half under part of a city in the West of England without causing any damage to buildings. Mr. Lloyd points out the important effect on subsidence of old workings in overlying strata. Although the strata above the seams previously worked may have settled to a position of rest, they will be more easily disturbed by subsequent workings than if they were in their original condition. It is usually found that the amount of subsidence in such cases is greater than is produced in virgin ground. The new subsidence may also break down pillars in the old workings and so cause serious damage.

In many cases minerals have been mined under the sea. In Britain coal is mined off the coasts of Northumberland, Durham, Carmarthenshire, Flintshire, Cumberland, and Linlithgowshire; and metal-mining has been carried on off the coasts of Cornwall and Lancashire. The workings that extend farthest seaward are probably those at the William Pit, Whitehaven, where in 1901 they extended 19,000 feet beyond high-

water mark. The effect of subsidence under the sea is to deepen the water, if the coast-line rises sharply, and to submerge a narrow strip of land if the coast-line is low.

The effect of subsidence on land-drainage depends on the shape of the surface. In an area of high relief, drainage changes may be trivial, even after considerable subsidence; but when the ground is low-lying, important changes in the drainage may ensue. In the Middle West of the United States there are areas where coal has been mined under prairie land which is so flat that the natural drainage is very sluggish. A subsidence of only a few feet causes large sheets of water to stand for months, to the great injury of farmers.

Near Wigan, Lancashire, there is a large area of land under water from which a few dead trees emerge. In this area, as the ground is flat and low-lying, the subsidence has been sufficient to prevent rain from flowing away and to cause it to form lakes.

Mr. T. C. Cantrill measured a subsidence in South Staffordshire. About two miles north-east of Walsall, at Stubber's Green, a lake has been formed in the interval between the date of the Ordnance Map (Revision of 1900–1) and the date of observation in 1911. The lake, covering approxi-

mately 97,750 square yards, is situated on a site shown as land on the map made ten years previously. The depth of the water is unknown, but is at least sufficient to float a boat. The lake is roughly rhomboidal and is bounded on the north-east by a high-road for about 250 yards. Across the road was a swamp also formed since the survey.

Mr. T. H. Whitehead noticed that on the western side of the Netterton Tunnel (canal) in Staffordshire, the subsidence has been about 40 feet. Immediately below the tunnel the coal has been left unworked, but beyond its margin it has been got, with the result that the land supporting the tunnel now stands up as a ridge, rising some 40 feet above the ground to the west, which has subsided. On the east of the tunnel the effect is similar but not so obvious.

Fissuring of the rocks caused by subsidence may allow the escape of water from a permeable bed, such as gravel, and cause wells and springs to become dry.

Many of the coal-seams mined in Britain are comparatively thin, e.g. 2 to 4 feet, and it is necessary to remove much additional material in order to allow room for the men to work, and more particularly for the underground roads. In the aggregate a mass of rock equal in bulk to half that of the coal

has probably been extracted. As the total output of coal in the United Kingdom from the earliest times to the end of 1928 is roughly 16,166 millions of cubic yards, and we have to add 50 per cent. to allow for the bulk of stone brought up with the coal, we find that 24,250 million cubic yards have been excavated by coal-miners since the earliest times. The volume of subsidence, however, due to coal-mining up to the present is but a fraction of this amount, because a great part of the excavation is filled up (1) by stowing waste, (2) by the breaking down of strata and resultant natural packing. Since coal-mines tend to become deeper as the mineral becomes exhausted near the surface, the amount of subsidence produced by mining will be less than in the past. Professor Galloway tells us that as much as 13·12 feet of strata can be entirely removed without any subsidence following, provided that the workings are not less than 2,624 feet below the surface. We already possess many collieries deeper than this and in the future we may expect new shafts to extend down to about 4,000 feet. With stowing, if Monsieur Fayol is right, there would be, as a rule, no subsidence at all caused by deep collieries. Instead there would be a belt of shattered strata up to 2,000 or 3,000 feet in thickness

and holding water like a sponge. Such a belt differs from a smash-belt made by Nature in its spongy character. Those formed by natural forces occur, as a rule, in regions of folding, where the rocks have been broken under the orogenic forces. These broken masses have been kneaded by enormous pressures and cemented by percolating waters into solid rock, as compact as the other rocks of the district.

By adding together the reserves of coal in England and Wales, as given by Dr. W. Gibson for each coal-field, we find the total to be 86,387,891,000 tons, of which over 2,000 millions are under the sea, off the coasts of Cumberland, Northumberland and Durham.

Supposing that the whole of this coal is eventually dug and that half its bulk of stone has to be excavated in order to extract the coal, the total future excavation in England and Wales would be about 126,580,500,000 cubic yards, under the land surface, that under the sea being omitted, and under Scotland 17,884,500,000 cubic yards. If the excavations were spread uniformly over the area of the coal-fields, which of course would not be the case, it would amount to 8½ yards over the entire area of 4,682 square miles. For Scotland

the excavation would amount to about 2½ yards over the area of the coal-fields, taken as 2,300 square miles. These figures apply to the future and are additional to the 24,250 million cubic yards already excavated.

The amount of subsidence cannot be estimated, because, not only would there be packing of the strata, but the depth of much of the excavation would be at depths approaching 4,000 feet from the surface, and this part might not produce subsidence at all. The waste, estimated at 50 per cent. of the coal, is to a great extent left in heaps on the surface, or spread about. As it is fragmental material it occupies much more bulk (see p. 70) than it did in the mines, and this will help to diminish the nett subsidence.

Salt deposits offer special problems of subsidence, for, as the mineral is for the most part pumped up in solution, and not obtained by mining, a cavity is left without any support from pillars; the only part left in the ground being the insoluble residue.

The British deposits of salt are situated in Cheshire, Worcestershire, Staffordshire, Yorkshire, Co. Durham, Lancashire, Somerset, Shropshire, the Isle of Man, and Carrickfergus (in Ireland). Of these much the best known are those of Cheshire.

The salt-beds of Cheshire are much thicker than coal-seams. Under Northwich the salt consists of two beds separated by from 20 to 26 feet of marl. The upper bed, the Top Rock, is more variable than the lower or Bottom Rock. Each attains a maximum thickness, at Northwich, of about 90 feet, but as a rule the Top Rock is much thinner than this and the Bottom Rock also varies, though to a less extent. What are apparently the same beds are found at Winsford, some five miles away; but the thickness is greater, being about 239 feet in all, while the greatest thickness of salt known in the country is found at Plumley, about three miles east of Northwich, where there is nearly 600 feet of salt. At Middlewich, Wheelock and Lawton, little is known of the thickness of the salt; but at Heatley (Lymm), about four miles east of Warrington, it is about 200 feet. The continuity of the beds has not been proved, but is highly probable; and the presence of salt-springs at Audlem, Dirtwich, and many other places, and of thick salt-beds near Whitchurch, points to an extension into Shropshire.

Brine-springs had been known for centuries at Northwich when, in 1670, the top bed of salt was discovered there and was mined from about 1730 until 1800. In 1781 the

lower bed of salt was found, and after 1800 became the main source of rock-salt. The quantity mined, however, has become very small in comparison with the salt obtained by the evaporation of brine and known to the trade as White Salt.

For a long time Northwich has been remarkable for its subsidences. Streets and houses fall in and require repeated repairs to keep them fit for use, and large meres (the flashes) have developed and are continually extending. These subsidences, which occur also in other salt-districts and particularly in Winsford, are due to the mining of rock-salt and the pumping of brine. The natural brine-springs removed, from the surface of the bed, a small quantity of salt dissolved by water percolating through the superincumbent rocks and forming a layer of brine over the material. The upper part of the layer was far from saturated, and it was this highest layer that oozed out at the springs and removed a relatively inappreciable quantity of salt. In 1533, 1659 and 1713 small subsidences were recorded, and they were probably due to the removal of salt by the springs, i.e. in three centuries there were three small subsidences from natural causes. More than a hundred times as much subsidence now occurs in ten years

as formerly in three centuries, the difference being caused by the action of man.

The causes of subsidence are two : (1) the falling in of old rock-salt mines, and (2) the removal of the salt in solution as brine. The first cause is now by much the less important. The most serious case of this kind was due to the collapse of a shaft at Willow-cum-Twambrook. The hole produced is about 450 yards in circumference.

The production of salt by the evaporation of brine has grown enormously. In early days the brine rose to a considerable height in the wells ; but, as production increased, the level was lowered until it fell to the surface of the salt. Afterwards the brine pumped came from streams that flowed over the rock-salt and dissolved it in their course until the water was saturated. The surface of the salt-bed became worn into deep gullies in this manner, and subsidences began to be noticed over the lines of the channels. Water, on reaching the salt, soon becomes saturated and then exerts no further solvent action ; but when it is pumped up, the space left is filled by fresh water, which dissolves salt to saturation, and a continuation of the pumping results in rapid solution of the salt. A striking illustration of the slowness of natural denudation of salt is the

case of the salt mountain of Cardona, in Spain, which is said to waste under atmospheric agents by only 4 inches a century.

At Northwich, a considerable part of the town is situated over the salt-deposits, and subsidences are naturally most noticeable amongst buildings. The Flashes (meres), when sounded, show troughs on the stepped sides, and may be 30 or 40 feet deep. If the earth is tenacious they may fall in suddenly; but more usually funnel-shaped holes arise, which widen by degrees. At Marston and near Dunkirk, Northwich, land and roads sunk 40 feet in the period from 1877 to 1888, and what were green fields are now covered by 15 to 30 feet of water. Numerous striking instances of subsidence are given by T. Ward and others. Ward writes that in 1900 the Dunkirk Lake was about 30 acres in area and was daily extending in spite of several scores of thousands of tons of earth and stones having been thrown in. The depth was from a few to 100 feet. The large flashes alongside the Weaver had been nearly filled up in 1898 with waste from Brunner Mond and Co.'s Chemical Works.

In 1880 the mines in the Dunkirk district were pumped very low and there was a great collapse, owing to the loss of the support afforded by the brine. At one time the

depth of water over the shafts was fully 200 feet, and for a long time it remained above 160 feet over a considerable area. The earth on all sides of the hole slipped in, and attempts were made to choke it by sinking over the site some old canal-boats full of cinders, as well as by putting in thousands of tons of dredgings from the Weaver and Manchester Ship Canal. Fully 100,000 tons of earth and rubbish have been dumped and over 250,000 tons of earth have slipped in; but the depth is 60 or 80 feet over a considerable area, and the land is still cracking and sliding. On the west, between 1880 and 1898, a lake of over 20 acres with a depth of 1 to 50 or more feet was formed. The Marston or Neumann's Flash covers more than 12 acres and is very deep in places. Both lakes are constantly extending.

The greater part of the insoluble residue from the solution of the salt remains below and helps to fill up the hollows with fine mud. This residue is about 25 per cent. of the whole mass. In the case of rock-salt mining there is, of course, no residue; but in this case the parts of the mass most free from impurity are chosen for mining.

Subsidence at Winsford first appeared in 1820, since when it has followed the same course as at Northwich. At the latter place

the lakes have little relation to the rivers, because they were initiated by the collapse of the Top Mines, which were grouped in clusters without relation to the surface-drainage. At Winsford, however, the floods began as pools on the river-flat, extending rapidly into a lake, through which the river runs. There are now three lakes at Winsford, the Middle Flash being of recent origin. The Bottom Flash ends at Winsford Bridge, which had been raised no less than 17 feet by 1880. Ashes from the salt-pans are constantly being deposited in this lake, but, although it is possible to keep some parts of it shallow, the subsidence is still growing. Doubtless the three lakes will eventually coalesce.

In 1898 Ward estimated that the total output from Northwich during the previous two hundred years was about 25 million tons of white salt and about 10 million tons of rock-salt. He considered that rock-salt contains on the average 25 per cent. of insoluble residue, and so the loss of rock-salt from Northwich previous to 1898 would be about 40 million tons, equal to 25 million cubic yards. I find that a similar calculation for Winsford, from figures given by Ward and Calvert, indicates a loss of 50 million tons, or $31\frac{1}{4}$ million cubic yards, from this district,

up to 1913 inclusive. From the entire salt-field of Cheshire about 143 million tons, or 88 million cubic yards, of rock-salt had been removed by the end of 1928.

Sinking of the ground will continue until all the salt has been removed. The depth to the salt is about 140 to 180 feet at Northwich, about 200 feet at Winsford, and about 370 feet at Lymm and Plumley, so that in Cheshire the depth of the salt is everywhere relatively shallow, and this of course gives less opportunity for the strata to pack themselves.

According to Ward, the average thickness of the salt in the four square miles worked at Northwich is about 162 feet. The maximum subsidence would therefore be a little less than 162 feet at Northwich. A greater subsidence is possible at Winsford, where the salt is about 239 feet in thickness, and still more at Plumley, where it is nearly 600 feet thick.

There is reason to believe that the salt-beds extend over a very much larger area than was known to Ward and Calvert, and the possibilities of subsidence in the district are greatly increased. Nevertheless, it will be a long time before pumping in the newly discovered districts can cause extensive subsidences. The quantity of salt in Cheshire

is so vast that it is likely to be many centuries before it is exhausted, and the full subsidence may never be felt. In that very distant future, however, there is a prospect of an area of some 200 square miles being reduced in altitude by an average amount of 100 feet, which would bring much of Cheshire below sea-level. Even if the sea were kept out by embankments the drainage-water would form a large freshwater lake, parts of which might be, say, 400 feet deep. Already the bottom of the largest flash at Winsford is at about sea-level.

In the Middlesbrough salt-field the output of salt, pumped as brine, up to the end of 1928 was 8,072,000 tons, which, supposing the rock-salt to have the average composition of that of Cheshire, would represent the solution of about 3,362,000 cubic yards of rock-salt. About one-third the bulk, or 1,120,000 cubic yards, would be left behind as fine clay to help to fill up the empty space. At Middlesbrough there is a thickness of from 863 to 164 feet of rock, much of it massive sandstone, above the salt. Probably, therefore, when subsidence begins the sandstone beds will break and pack themselves, so that the volume of subsidence will be less than that of the cavity formed. At present there are, presumably, caverns of a

total volume of about 3,362,000 cubic yards, about one-third filled with mud and the remaining space with brine.

Total Subsidence.—On page 37 an estimate is given of the amount of rocks and minerals mined since the earliest times. Some of this material may be obtained from so great a depth that subsidence will not be produced; also subsidence does not seem to be marked in the case of many metalliferous deposits, where the workings are inclined at a high angle and are in very massive rocks. As a very rough approximation we may perhaps take the average subsidence due to mining at all depths at from 30 to 40 per cent. If only 30 per cent. the effect on the surface is as if 5,910 million cubic yards of rock had been removed, a quantity that can be added to that quarried. The remaining 70 per cent. of space underground, a volume of 13,790 million cubic yards, will be filled with broken fragments of rock, forming masses of breccia with the interspaces filled by water.

CHAPTER V

LONDON

London, the largest city in the world, and with a history extending over some two thousand years, offers an excellent field for a study of the changes wrought by Man on Nature. Before Man settled on the site of London the district formed an extensive marsh, stretching southward as far as Stockwell and New Cross. Lambeth, Kennington, and Newington were mud-banks, covered at low tide, while at high tide the river flowed directly from Lambeth to Deptford.

On the north of London the Hampstead and Highgate Hills rise to 440 and 420 feet respectively, and the ground in front, sloping towards the Thames, was cut into by small streams, the Westbourne, Tyburn, Holeburne (the lower part called the Fleet), and the Wall Brook. The last rose on Moorfields, the others at the foot of the Hampstead and Highgate Hills. The higher ground between the streams forms hills

such as Notting (or Camden) Hill, 130 feet high, and Tyburn Hill, about 90 feet; then beyond the Tyburn is the site of Oxford Circus, 90 feet high. Farther east we have Ludgate Hill with a low plateau extending to the valley of the Wall Brook, east of Cheapside. This plateau was about 59 feet above sea-level. Beyond the Wall Brook comes Cornhill, and it is probable that this patch of rising ground, sloping eastward to the Lea Marshes, formed the site of the first settlement. To the north of the settlement the Finsbury Marshes extended to the forest that covered Middlesex and Hertfordshire and spread far beyond those counties. On the other three sides the settlement was protected by the Wall Brook, the Lea, and the Thames. In those days the tide reached far up the river and overflowed what is now dry land, both to the north and the south of the present bed.

A relic of the Westbourne is the Serpentine. The river used to flood Knightsbridge, and opposite Albert Gate a stone bridge was erected, it is supposed, by Edward the Confessor. Lower down the stream was a swamp called the Five Fields, now occupied by Sloane Street and Chelsea Bridge Road. At the present time the Ranelagh

Sewer carries the river-water in the general direction of the old stream. The sewer was completed in 1834, and can be seen crossing Sloane Square Station.

The Tyburn, or Ayebrooke, flowed through Regent's Park, where the junction of a tributary is still to be seen as a fork in the lake. The stream crossed Piccadilly at Brick Street, where there used to be a water-wheel, and flowed under Buckingham Palace. It then divided into three arms, the middle one turning mills at Abbey Gardens, Westminster. The Abbey stands on its delta. At Marshall and Snelgrove's, Oxford Street, a bridge over the old river was found, also the metalling of the old Tyburn Road, 11 feet below the level of Oxford Street. In 1238 a conduit here supplied water to the City. Finally, in 1812, the stream was incorporated with a sewer.

The Fleet, or Holeburne, was the largest tributary, and its lower part was a tidal estuary up which, at one time, ships sailed as far as Holborn Bridge. Stow says that it was of such breadth and depth that ten or twelve ships' navies at once, with merchandise, were wont to come to Fleet Bridge and some to Oldbourn Bridge. It was still navigable as late as the reign of

Edward I. In 1666 the river was canalized, but barges still went up to Holborn Bridge, and a drawing dated 1765, preserved in the Guildhall, shows them moored by Bridewell Bridge. Holborn Bridge, of stone, had houses on both sides in 1560, and in 1673 it was rebuilt by Sir C. Wren. In 1735 the Corporation began to close in the stream, and in 1855 the Fleet was absorbed into the Metropolitan Sewer and is now covered entirely, from source to outfall.

The Wall Brook once flowed past the villas of the City merchants. The earliest map of London, that by Agas in 1560, was published long after the brook had been covered in, about 1473, so there is no record of it on any map. It flowed from the fens of Moorflat, through the Wall, then across the site of the Bank of England and by the Mansion House. The building of the Wall across the brook ponded up its waters and caused them to form the morass of Moorfields. The peaty alluvium of this district is a result of the Roman Wall. At the National Safe Depository the Wall Brook was joined by the Langbourne Water. It was of considerable width at its mouth, and was navigable, and barges went up as far as Bucklers-

bury. The brook flowed in a ravine at least 30 feet deep, and Roman remains have been found at that depth. Enormous quantities of broken vessels and kitchen utensils have been discovered, showing that the ravine was a receptacle for refuse. In 1288 and 1388 the Common Council made requisitions for cleansing it, and in 1598 Stow speaks of it as having been vaulted over and paved and its course forgotten. The soil, says Mr. Greening, has been getting drier in recent years, owing to the pumping frequently resorted to on the erection of new buildings and the construction of deep basements (for instance, Lyons' café in Throgmorton Street extends 42 feet below the surface) and through the action of shallow wells in Queen Victoria Street.

Fitzstephen, in 1190, wrote: "There is also about London, on the North side, excellent suburban springs, with sweet, wholesome, and clear water that flows rippling over the bright stones; among which Holy Well, Clerkenwell, and Saint Clement's are held to be of most note. These are frequented by greater numbers, and visited more by scholars and youth of the City when they go out for fresh air on summer evenings." For centuries these springs supplied London's needs, until they became

contaminated and the first public waterworks was constructed in 1512 at London Bridge.

There are few traces of pre-Roman settlements. The first Roman wall round London took in about 70 acres between Wall Brook and Mincing Lane, on what was practically an island. As the town extended a second wall was built to take in a much larger area, and this wall was more than 3 miles long, but included gardens and open spaces.

The Romans dug up the Thames alluvium to make into bricks, and this practice has since been maintained, until nearly the whole of the alluvium that covered the site of the growing town has been removed and the underlying gravel exposed. The alluvium removed was burnt into bricks and tiles to build London, and, although a great proportion of the bricks have since been destroyed, their fragments have accumulated to raise the general level.

Neither the alluvium nor the accumulated *débris* has a uniform thickness and the ground-level has been altered all over the area. The level has been raised in one place and lowered in another. Broadly speaking, hills are lowered and valleys raised, partly by loose materials working down

slopes, partly by the action of engineers in lessening gradients on roads, partly by dumping waste materials in hollows. Nevertheless, although hilly ground becomes somewhat flattened, the original shape of the surface is, as a rule, only toned down, not obliterated. For example, the ravine of the Fleet has been filled up, but the steep gradient at Ludgate Circus still shows where the river used to be.

On the average there is from 12 to 15 feet of *débris* or "made ground," as it is usually called, within the City of London, with a maximum of about 25 feet, and outside the City about 3 to 4 feet. This is in accordance with the greater age of the City, and confirms the idea that the surface level of a town rises as the town grows older.

An area of about half a square mile in Fulham and another of about a quarter of a square mile in Battersea Park have lost alluvium without gaining an accumulation of waste, with the result that these areas are below high-tide level.

Not only has Man deposited a mass of *débris* over the whole site of London, but he has disturbed the subsoil and frequently the rock below. In the construction of sewers, underground railways, wells, and

the foundations of buildings, he has dug out considerable quantities of materials, which have been carted away for the most part, although some have been used locally to fill up other excavations. The level of the underground water has been lowered considerably by pumping, also the atmosphere has been brought into contact with masses of buried strata, and is able to oxidize and hydrate them to a limited extent, as if they were at the surface. Moreover, tunnels generally require lining with brick, concrete, or metal, and in this way a great volume of man-made materials become buried in the natural rocks. The extent to which the strata under London have been excavated and the depth to which Man's disturbing influence penetrates is well illustrated by Gomme, who writes: "People have little idea of what is built underground in London. Thus few streets have been more extensively utilized either above or below ground than that opposite the Mansion House. Immediately below the surface are the subways for gas and water-pipes; the house-drains and sewers are beneath these; at a still lower level is the railway, and below this again, the large low-level intercepting sewer. Between Lambeth Hill and New Earl Street the

whole of the ground beneath the street is completely honeycombed with these several structures, which extend the entire width of the street, from a depth of 30 feet below, up to within 18 inches of the surface. Few people passing along the street are aware of the network of iron pillars and girders which lie only a few inches beneath their feet. At Chatham Place, Blackfriars, are four large structures crossing each other in various directions below the surface; at the lowest depth, about 40 feet, is the low-level sewer, over which crosses the main Fleet Sewer, formerly a tributary stream of the Thames; above this, the Metropolitan District Railway; and above this again, the subway with its gas, water, and other pipes."

The quantity of material excavated within the London area is very great. To form an estimate of the amount we must consider the quantities dug out of wells and boreholes, in making sewers, underground railways and passages, and the foundations of buildings.

Mr. A. S. Foord has shown that no deep wells existed in or near the City of London until, at earliest, the middle of the eighteenth century, although deep wells of great antiquity are known in many country castles. I have estimated that the 901 wells and borings known within London

City and County, in 1913, represent the excavation of 70,500 cubic yards of material.

The total length of London sewers is not known; but generally a local sewer underlies each street, and in 1911 there were 2,200 miles of streets within the Administrative County of London. There are also sewers draining into the system from beyond this area. In addition the Main Intercepting Sewers are 180½ miles, and the Stormwater Sewers 189½ miles long, according to Sir Maurice Fitzmaurice. Together these main sewers are about 370 miles long. Taking some figures given by Sir J. W. Bazalgette, we shall probably not be far wrong in estimating the total excavation from the main intercepting and stormwater sewers, 370 miles in all, at 14 million cubic yards.

Mr. B. Baker gives details of the Metropolitan and District Railways, from which we estimate that the total excavation was 4,119,000 cubic yards. This is probably too small because the extra depth of parts of the railway cuttings cannot be estimated for lack of data.

We cannot give an estimate of the amount of excavation involved in laying the local sewers, the gas mains, the water-pipes, and in other street excavations. Owing to the

thickness of "made ground," which we have seen averages from 12 to 15 feet within the City and about 3 or 4 feet within the County of London, some of the shallow excavations will be entirely in this deposit. The turning over of "made ground" affects it inappreciably; the constituents will be more thoroughly mixed together and the fragments broken smaller, but that is all. Where the excavation goes through the "made ground," as may be seen almost daily when the streets are "up" for repairs to a drain, or for the foundation of a new building, the natural subsoil or rock becomes mixed up with the artificial soil. In the course of centuries this process adds to the thickness of "made ground," which may be expected to extend downwards, because foundations tend to be dug more deeply and drains to be laid at lower levels than formerly. Hence "made ground" increases not only by accretions of *débris* from above, but also by incorporation of the strata below.

Some account of the docks is given on page 104. We have no estimate of the amount of excavation they represent, but we may include it with the minor street excavations and allow 3 million cubic yards for them all, a figure probably too low.

The Victoria, Albert, and Chelsea Embankments represent both excavation and accumulation, the latter predominating. The excavation is probably about 336,000 cubic yards (see p. 103).

Adding up the several items, we find the excavation within the City and County of London to be as follows:

	Cubic Yards.
From wells and borings	70,500
The Main Intercepting and Stormwater Sewers	14,000,000
The Tube Railways (to 1914) . .	7,143,000
The Inner Circle	4,119,000
The remaining railways	20,899,000
The Greenwich Footway, the Rotherhithe and Blackwall Tunnels	513,967
The Victoria, Albert, and Chelsea Embankments	336,000
Docks, Drains, Foundations of Buildings, etc., at least	3,000,000
Total	50,081,467
say	50,000,000

Spread uniformly over the 116·9 square miles of the Administrative County of London, the average excavation would amount to about $3\frac{3}{4}$ inches. The excavations under London do not produce subsidences, as is the case with mining operations, because the ground is carefully supported by engineering structures. The underground excava-

tions therefore are spaces filled with air or water. There may, however, be a small amount of subsidence due to the slipping of gravelly foundations under weighty buildings, as is said to be the case at St. Paul's, and also to the solution of chalk by the water pumped from borings.

In its natural condition the Thames was bordered, at what is now London, by extensive marshes. It is uncertain if there was a bridge over the river in Roman times, although one is mentioned by Claudius Cæsar, but Mr. Belloc in his *Stane Street* gives reasons for thinking that there was. However, the first historical bridge at London was completed in 1016, and by 1209 a stone bridge had been built. For six hundred years this was the only bridge over the Thames at London, and it was rebuilt in 1810. According to Mr. Greaves, an immense quantity of ballast was dredged from the Thames in a promiscuous manner to ballast the Tyne colliers for their return journey. He considered (in 1877) that the materials obtained for this purpose exceeded that dredged systematically since 1810. The hills of ballast may still be seen on the banks of the Tyne, though most have been removed recently, but large as they were, they

represented only a part of the dredged mass, for great quantities were thrown into the sea on approaching the harbour mouth. The hollows left in the bed of the river would be subsequently filled by detritus swept down the Thames.

The Thames embankments are perhaps the largest engineering structures in London. The Victoria Embankment was made as part of the scheme for building intercepting sewers. Previously, however, the river had been embanked at the Houses of Parliament, at Greenwich Hospital, and at some other places, to a total length of 14,800 feet (nearly 3 miles), the earliest being made by Mylne, on the Middlesex shore, in 1767. Also private quays were made from Blackfriars Bridge to the West India Docks, and others on the south side, having a total length of 39,000 feet (nearly $7\frac{1}{4}$ miles), or about 10 miles in all. These embankments are comparatively modern; but there are some on the lower Thames of the making of which there is no record, although it is customary to attribute them to the Romans. They are about 100 miles long on the two sides of the river, and they exclude tidal water from about 30 square miles of land, the surface of which lies 4 to 7 feet below Trinity Highwater

Mark. Mr. Redman thought that the lower reaches were embanked in the reign of Henry VI, and that before they were made, the high water at London probably did not exceed that at sea, whereas there is now 5 feet difference in tidal-level between Sheerness and London Bridge, a distance of 48 miles. This effect has been continued as far as Teddington, 19 miles from London Bridge, by the modern embankments.

The Victoria Embankment is about $1\frac{1}{4}$ miles long, and covers $37\frac{1}{2}$ acres of mud-banks that have been reclaimed from the river. A subway carries gas- and water-pipes. Edwards (see Gomme) states that the embankment required 1,872,000 cubic yards of materials. The excavations amounted to 144,000 cubic yards.

The Albert Embankment is 4,300 feet long, and has its foundations 30 feet below Trinity Highwater Mark. These two, together with the Chelsea Embankment, are about $3\frac{1}{2}$ miles long, and have reclaimed about 52 acres of mud-banks. We have figures for the Victoria Embankment only, but if the other two are similar in their proportions the three would represent an excavation of 336,000 cubic yards and an accumulated mass of bricks, stones, and earth of about $4\frac{1}{3}$ million cubic yards.

There are also the various quays mentioned above, for which we have no figures.

In 1914 the Port of London docks covered 704 acres, with 29 miles of water-quays. These figures, however, include the new Albert Dock and the Tilbury Dock, beyond the boundary of London. No estimate can be given of the total amount of excavation from the London docks. In the case of the south dock of the West India group the excavation was 1,600,000 cubic yards, and the material was deposited on land. The dock wall contains about 158,000 cubic yards of masonry, half being bricks and half concrete. In the original Victoria Docks the walls, including the face-walls and coping, were all made of concrete, of which 450,000 cubic yards were used.

The materials excavated from the London railways and sewers seem to have been disposed of, for the most part, by dumping them on the low marshy lands of Essex, down the Thames estuary, or into the sea; but this was not always done. The surplus from Marylebone Station and approaches was deposited at Neasden sidings, and the material from the Piccadilly Tube at Hertford, in old ballast-pits.

A very different form of denudation is effected by solution of rock. The Metro-

politan Water Board draw more than $5\frac{1}{2}$ million gallons of water daily from chalk below the County of London, and there are also private wells obtaining water from the same area. A million gallons of water pumped from the chalk is said to contain $1\frac{1}{4}$ tons of chalk in solution, occupying 17·6 cubic feet. The Water Board therefore alone remove 96·8 cubic feet of rock daily from beneath London, or 1,306 cubic yards per annum.

A considerable amount of building-stone is destroyed in London by solution. Rain carrying carbonic and sulphuric acids, the latter derived from the burning of coal and the former from the same source and from animal respiration, has solvent powers on limestone and some other rocks. The chief building-stones of London are lime-stones, and these perish rapidly, while the mortar between bricks requires periodical replacement.

While carbonic acid dissolves the stone and removes it in solution in rain-water the sulphuric acid forms gypsum (sulphate of calcium), a substance only moderately soluble. This is the reason for one of the characteristics of London scenery—namely, the sharp alternations of black and white seen on many public buildings. The black patches represent a deposit of soot, while the white areas are parts that have been

more exposed to the rain, so that the soot is washed off. The whiteness is due to the formation of gypsum.

Calcareous sandstones also are liable to decay, the stone being left in a powdery condition by the solution of the cementing material. Even igneous rocks do not escape. The so-called Norwegian "granite," for example, becomes spotted with rusty stains caused by the oxidation of the iron present in the rock.

Although Man has been an active agent of denudation in London, he has greatly hindered natural denudation. The greater part of London is protected by pavements and roofs from the action of atmospheric agents such as frost and rain. Even in open spaces there is often an accumulation of "made ground" protecting the natural surface below. The rain that falls on London runs off the protected surface into sewers and so into the Thames; whereas before London was built the rain was collected into streams, and these were able to denude their channels in the usual manner. Even in the case of gardens and parks erosion must at present be very slight, for the open spaces are too small to enable the water to collect into streams, and erosion will be reduced to little more than

solution by rain-water, and the removal of a little soil into the sewers.

Having now considered the quantities of rock removed from London we have to find out what additions have been made to the area. In the early history of London there is scarcely any mention of engineering feats of importance; sewers, railways, boreholes, are all of them modern innovations.

In the Middle Ages a burgess's house was a wooden framework with interstices filled with plaster and a roof thatched with straw or reeds. The natural result was that devastating fires were frequent. In the first year of Stephen's reign (1135) a great fire destroyed St. Paul's and raged from London Bridge to St. Clement Danes. One consequence was that in 1189 an Assize of Building was drawn up, ordering citizens to build houses with party walls of stone up to a height of 16 feet, but this order seems to have had little effect and, in 1212, a new ordinance following another severe fire ordered new houses to be covered with tiles, single boards, or lead, instead of thatch. Until long after this period stone houses were so few that they were used as direction marks, much as we now speak of The Elephant and Castle, or The Angel, Islington. Between 1350 and 1450 a marked

improvement in wealth led to the erection of houses of two or three storeys. In the reign of Richard I, windows were mere apertures. Glass was only used by the most opulent and is first mentioned as a regular import in the reign of Henry III. London was nevertheless much in advance of continental cities in comfort and cleanliness. At the end of the twelfth century the population was estimated by Peter of Blois at 40,000; Hallam put the population in John's reign at between 30,000 and 40,000, and in 1377 a poll-tax gave it as 44,700.

The old inhabitants of London, Westminster, and the country villages now absorbed into London County, accumulated a mass of *débris* round their houses. Ordinary house and trade waste was dumped in the nearest available place, not uncommonly the public road. There are many complaints in old town records of streets becoming impassable owing to the accumulation of rubbish thrown out of the houses. For example, in the prosperous borough of Nottingham, the streets, about the fifteenth century, were blocked with piles of cinders cast smoking hot from the bell foundry and the iron workshops, and with heaps of corn which the householders winnowed by throwing it from an upper win-

dow. Again, the important city of Norwich had its market-place still unpaved in 1507, but a judicious order was issued that no one should dig sand-holes there without the Mayor's licence.

Household and other refuse, then, was trodden down in the streets and gradually raised the ground-level under the town, the bulk being added to by the ashes of buildings destroyed in the fires. Outside the town a certain amount of digging for sand, clay, and gravel took place, and as the town grew, these pits were filled with rubbish and built over. Also, as we have seen, the stream-beds, such as the Wall Brook, became filled up with refuse.

Sewers were originally intended to replace natural streams and carry off the rainfall, and in London up to 1815 it was a penal offence to discharge sewage into sewers. Later, from 1815 to 1847, it was permissible, and after 1847 it was compulsory to do so. During the six years 1847–53 some 30,000 cesspools had been abolished and the drainage turned into the Thames. The pollution of the Thames became such an insufferable nuisance that at last, between 1856 and 1874, intercepting sewers were built, on both sides of the river, to carry the sewage to Barking

and Crossness, respectively 11 and 13 miles below London Bridge. Large reservoirs were built to contain the sewage so that it need only be discharged at ebb tide. Up to 1890, crude sewage was discharged into the estuary, but since that date it is precipitated by chemicals, and the sludge carried down the river in vessels for 55 miles, and deposited over a distance of 8 to 10 miles in the Black Deep. In the year 1913–14 the sewage treated was 104,567 million gallons, which required 19,702 tons of lime and 5,009 tons of ferrous sulphate. The sludge produced and sent to sea weighed 2,660,000 tons, containing 204,634 tons of solid matter, or 7·69 per cent. of the sludge.

In 1911–12 the house and trade refuse collected within the County totalled 994,916 tons. As the trade refuse from Westminster and part of Paddington are not included, we may take the round figure of 1,000,000 tons for the whole of London.

Street sweepings consist of *débris* from the pavements, iron from horses' hoofs, horse-dung, etc. With the rapid replacement of horses by motors the sweepings change their character, the tendency being probably to diminish the bulk by the loss of much organic matter. In 1867 Dr. Lettenby analysed the sweepings from a

London stone-paved street and found that it contained, on the average, 47·2 per cent. of organic and 52·8 per cent. of inorganic matter. Conditions have changed greatly since 1867. The loss of organic matter through the replacement of horses by motors is more or less counterbalanced by the growing use of wood and asphalt pavements. Mud from a wood pavement contains about 60 per cent. of organic matter.

The ways of disposing of house, trade, and street refuse are diverse and new plans were constantly being adopted. Formerly it was customary to dump the refuse on waste lands, but this created a nuisance and is rapidly falling into desuetude. To mention two instances only, the large gravel-pits at Wheathamstead and at "The Twentieth Mile" near Hatfield, in Hertfordshire, are largely filled up with London rubbish brought out by train, the trucks being loaded with gravel and sand for the return journey. A goods-train came to Wheathamstead daily, loaded with waste to be deposited in the old workings. This has now been stopped for three or four years, owing to the nuisance it created, but some 75,000 square yards (15½ acres) of land were filled up level with the general surface to a depth of about 20 feet. In the

case of the Twentieth Mile pit, an area of about 56,000 square yards ($11\frac{1}{2}$ acres) has been filled up to a similar depth. In time, weeds, chiefly nettles, grow over the waste and sooner or later the organic matter will be decomposed and destroyed, leaving the mineral matter, consisting of coal cinders and ashes, bits of crockery, tin-cans, fragments of metal, slate, etc., etc. The atmospheric agents will turn the iron into ferric hydrate, which we may expect will form a cement to the more stable fragments, the final result being a breccia cemented by ferric hydrate, a kind of iron-pan. The ground, of course, will sink greatly as the organic matter decays. If we consider the proportion of clinker produced by a refuse destructor we may expect about 70 per cent. to disappear and 30 per cent. to remain permanently.

The Cities of London and Westminster send all their street-sweepings in barges down the Thames and dump them on the marshes bordering the estuary. There the rubbish helps to raise the ground-level above tidal waters. However, street-sweeping has been reduced to a minimum by efficient flushing of the streets, and most of the refuse now passes into the sewers.

House refuse contains garbage, bits of

leather, metal, pottery, and an endless variety of odds and ends, and also cinders and ashes from the grates. Until recently the refuse was largely in demand for the making of stock-bricks, in which it used to be an essential ingredient. Of late years, however, destructors have been built to deal with the waste as a whole, and the stock-brick trade was gravely threatened until it discovered a substitute (p. 117). The residue from a destructor is clinker, about 25 per cent. by bulk and from 25 to 33 per cent. by weight of the original waste. Clinkers vary greatly in character. In some cases the rough lumps are used for "hard-core" (i.e. as a foundation for roads); in other cases the clinker is cast into paving-stones, which are eventually ground to powder under the traffic.

Beneath a large town the "made ground" tends to level up not only the natural hollows, but also the excavations made by previous generations. The clay, sand, or gravel dug out in olden times for bricks, mortar, pavements, etc., has been used on the spot, for there was little transport before railways were built, and the worn-out *débris* therefore remains in the "made ground" not far from the place from which the raw materials were taken. The thick-

ness of "made ground" is roughly proportional to the age of the town, as is well shown by London. Under the ancient city we find the greatest thickness and a diminution as we pass from the centre, with local thickenings where towns and villages were long established before they were absorbed into the metropolis.

All materials brought into London through the centuries contributed their quota to the "made ground." For example, the ashes of coal and wood fires have accumulated there for more than six hundred years. Fortunately there are statistics of the quantity of coal brought into London at intervals from 1600 onwards. From 1776 to 1813, 1820 to 1889, and 1903 to 1912 we have annual figures. By plotting a curve it is possible to fill in the gaps in the statistics, and the result is that during the three hundred and twelve years from 1601 to 1912, inclusive, the coal brought into London amounted to about 846 million tons; or say that 850 million tons have been brought in from the earliest times to 1912. Suppose the ash to average only 5 per cent. of the coal, it would amount to 42½ million tons, besides much half-burnt coal. The proportion of the latter has diminished of late years.

In considering the figures we must remember that the area to which they apply has varied. It is probable, however, that in the earliest records villages and towns near the London of those days, such as Fulham, Greenwich, or Tottenham, are included in the supply received by London, for coal was sent from Newcastle by ship, and London would naturally supply the adjacent country. The area covered by the earlier statistics may therefore be not very different from that to which the figures for 1903 to 1912 apply—namely, to Greater London, comprising the City and County Police Districts, with an area of 692·9 square miles. The coal ashes therefore have been deposited over an area considerably larger than the City and County of London.

It seems a safe assumption that the ashes were disposed of locally, and became, sooner or later, part of the "made ground." Some of the ashes were incorporated with the "made ground" directly, but for at least a century ashes, cinders, and other household refuse have been taken in barges, either up or down the river, to be made into stock-bricks. The bricks were used in London buildings; and when, in course of time, these were destroyed, the broken bricks containing the ashes became part

of the "made ground." Probably little coal was used in the country districts, because, until recently, the scattered population needed little fuel except wood. The refuse from scattered houses would find its way into the fields and be ploughed into the soil.

All organic substances, such as food, leather, or wool, contain a proportion of inorganic ash, and after decay the ash is left in the soil (or clinker, if put into a destructor), while the volatile ingredients return to the atmosphere. The soluble parts of the ash will be washed by rain into the rivers; the insoluble parts remain behind permanently.

The numerous fires that have devastated London through the centuries must have added a large amount of ashy material to the "made ground." Refuse destructors are a comparatively modern innovation, and even now probably not more than half of the waste products of the city are burnt in them.

We must also remember that before 1815 the sewage was entirely, and until 1847 partly, retained in cesspits. According to Henry Jephson, in 1841 there were 270,000 houses in London, most of which had cesspools beneath, while a large number had

two, three, or four. Some of them were so large as to be called "cess-lakes." Parts of West London were literally honeycombed with them. Hundreds, even thousands, had no drainage whatever, but the greater number overflowed. Further, Jephson, in 1907, quotes Mr. Cholwick as saying that 50,000 persons are buried annually in spaces not exceeding 203 acres in the aggregate.

Until about 1885 the only type of brick used in London was the stock-brick, while on the other hand this brick was scarcely used elsewhere. The chief centres of the industry are at Sittingbourne and between Southall and Slough. The waste from London's dustbins was sent in barges by river and canal, and stacked on waste ground for a time, until much of the organic matter had decayed, which greatly diminished its bulk. The residue was then screened and sifted to separate the fine ashes from the "breeze" (small cinders). In the spring an 18-inch layer of the fine siftings (called "soil") was spread over 6 feet of clay and chalk, and the whole thoroughly mixed and made into bricks. Before burning, the composition of the brick is "earth" (clay and "soil" mixed) 81, chalk 13½, and carbon 5. The "breeze" was used to start the kilns, but most of the heat was pro-

duced by the slow combustion of the "soil," which contains about 37 per cent. of carbon. A thousand bricks required 7 cwt. of "soil" and 3 cwt. of "breeze," while a ton of refuse contains 3 cwt. of "breeze," 10 cwt. "soil," and 7 cwt. large refuse ("hardcore"), consisting of all manner of articles, ironware predominating, but to a large extent organic. The "hardcore" accumulated in vast quantities, and was frequently used to fill up the clay-pits. The iron and organic matters oxidize, the slow decay taking years, and the bulk diminishes. For a century the mode of manufacture remained unaltered. After about 1870 a deterioration in the quality of "soil" set in, due, in part, to the decrease in the proportion of ashes to other refuse, in consequence of improved housekeeping; but in part to a deterioration in the quality of house coal. In 1899 complaint was made that the value of "soil" had gone down 7 per cent. during the previous twenty years, apart from the increased proportion of large and useless refuse. Moreover, the London vestries began to put up refuse destructors and burn their waste. Finally, people living near the brick-fields became more fastidious and complained of the smell of the decaying

refuse. As a result the stock-brick trade was threatened with extinction, until coal-dust and coke "breeze" were tried and proved to be better than the refuse, only $2\frac{1}{2}$ cwt. of coal-dust being needed per 1,000 bricks instead of 7 cwt. of "soil."

So long has this industry been carried on that brick-earth has been nearly worked out as far up the Thames as Windsor. Originally brick-earth covered the Thames gravels to a depth of 4 or 5 feet, and this has been removed nearly everywhere. Nowadays London Clay with chalk added is used for the bricks. In 1854 the production of stock-bricks in the London area was 130 millions, and in 1899 about 500 millions, the latter number requiring about 2 million cubic yards of clay and chalk.

Mr. A. L. Leach has given an account of a chalk mine at Wickham, Kent, that yielded 100,000 tons of chalk, between 1853 and 1903, for use in the manufacture of stock-bricks. There is a shaft about 80 feet deep, and the chalk was worked in galleries supported by large pillars.

Stock-bricks have no longer a practical monopoly of the London market. The Fletton (Peterborough) bricks are now supplied in immense numbers to the metropolis. However, the Peterborough brick-

trade only commenced about 1887, and up to, say, 1890 the stock-brick supplied London almost exclusively.

Almost all the household refuse of the metropolis remained in the area, being either directly trodden into the ground, deposited in old pits, or absorbed into stock-bricks that were used up locally.

Calculations based on the Census figures indicate that the numbers of bricks in existing buildings, tunnels, etc., in the County of London will certainly exceed 17,000 millions, and, reckoning 395 bricks to a cubic yard, this represents 45⅓ million cubic yards of brickwork, or sufficient to cover 14½ square miles to a depth of a yard.

The ancient buildings of London, with few exceptions, have been destroyed, and the fragments remain for the most part in the "made ground." By taking the number of houses at different dates and allowing for the average life, it would be possible to estimate roughly the amount of broken masonry now incorporated in "made ground." It would, however, be very difficult, and the same result can be obtained by estimating the bulk of made ground and finding its average composition. This latter investigation remains to be carried out. In estimating ancient masonry

we have to remember the closer packing of buildings in the older days. So late as 1850 it was permissible to build on spaces at the backs of houses, and so great heaps of buildings existed, absolutely covering the ground, back to back and side to side, so long as one could be fitted in. This packing led to more frequent and more disastrous fires and so diminished the average life of buildings. On the other hand modern buildings contain more masonry than the older ones, as they are on the whole more massive and higher, and this compensates for the open spaces between them.

We have few data relating to the number of houses in London at different times. In the reign of James I, when the population was about 150,000, the number of houses was about 17,000, and these were for the most part built of brick below and timber above. In 1836 Mammatt estimated that there were 400,000 houses in London. "London Statistics" gives the dwelling-houses in 1911, including those under construction, as 607,854, besides other buildings.

London has now been described in some detail from the human geological aspect. One or two points remain to be mentioned. There has been a certain amount of denuda-

tion due to the cutting of roads, especially in the hilly region around Highgate and Hampstead; but not to a great extent, for on the whole London rests on flattish ground. Moreover, any cuttings now made would be to a considerable extent in "made ground." The temperature of London has become warmer by several degrees in consequence of the heat generated by Man and other animals, and by the burning of fuel. Doubtless the drainage of the old marshes has had a similar effect.

The geological activities of Man on the site of London are similar to those on the site of any village or town; although there are differences in detail. Only in the largest cities are there underground railways or deep-seated main sewers. But the growth in elevation of each centre of population on its own *débris* is the outstanding feature. Exploration of ancient cities in various parts of the earth has shown that on the average they deposit a foot of *débris* per century, and this agrees with what we know of London. It would be interesting to check the figures in various British towns. In mining centres subsidence may neutralize elevation due to accumulation, but the formation of "made ground" takes place just the same.

CHAPTER VI

MAN AS A ROCK-MAKER

It may seem absurd at first sight to speak of rocks made by Man; yet if we remember that to the geologist a rock is any solid substance that enters into the composition of the crust of the earth, we see that many artificial things, such as embankments, colliery dumps, or masses of brickwork, come under this definition.

Rocks are divided by geologists into four classes, as follows:

1. *Igneous*. Rocks that have been melted, e.g. granite, lava, trap-rocks.

2. *Clastic*. Composed of fragments of previously existing rocks or minerals, usually, but not always, sorted by water, e.g. sandstone, clay, some limestones, morainic material, volcanic ashes. Also *Æolian*, a small class of rocks produced by wind-action, e.g. sand-dunes.

3. *Metamorphic*. Rocks belonging originally to other classes, but subsequently altered

greatly by heat, pressure, or water-vapour, or by all of these agents. They have undergone radical chemical and physical changes, e.g. gneiss, and schists of various kinds.

4. *Chemically formed.* Formed as the name implies, e.g. some limestones, gypsum, rock-salt.

Man-made rocks can be grouped into the same classes.

1. Examples are glass, slags, metals.

Glass and slag are similar to the volcanic rocks (i.e. igneous rocks poured out by volcanoes) called obsidian and pitchstone. The resemblance is often very close, and a fragment of black bottle-glass is practically identical in appearance and microscopic structure with obsidian. Slags are more like pitchstones, showing under the microscope incipient crystalline structure.

Igneous rocks may be divided into four groups according to the amount of silica they contain. The groups are (1) Acid, with from 66 to 80 per cent. of silica ; (2) Intermediate, with from 55 to 66 per cent. of silica ; (3) Basic, with 40 to 55 per cent. ; and (4) Ultrabasic, with less than 40 per cent. of silica. Each of these groups is divided into (1) Volcanic, (2) Hypabyssal, (3) Plutonic, according as the rock was (1) erupted at the surface ; (2) formed as

dykes, sills, or laccolites, at a moderate depth below the surface; (3) cooled very slowly in great masses and deep down in the earth's crust. In consequence of their mode of formation volcanic rocks are glassy or partly crystalline; hypabyssal rocks are crystalline but have a fine-grained texture and frequently contain large crystals in a matrix of fine materials; plutonic rocks have cooled very slowly under great pressure and therefore have usually a coarse-grained texture.

There do not seem to be any artificial representatives of the coarse-grained igneous rocks of deep-seated origin, such as granite.

Apart from the existence of such rare substances as native gold, platinum, copper, and mercury, the metals do not occur uncombined in Nature. Native iron exists as a mineralogical curiosity, chiefly, if not entirely, in meteorites, but the production of millions of tons of iron, steel, copper, lead, zinc, brass, and other metals, is one of the greatest works of Man. Just as a mass of meteoric iron would be classed as a rock, so we may regard these metallic masses as rocks, and, since they are produced by smelting in furnaces, at great temperatures, they would fall into the igneous division. Also they belong to the ultrabasic group.

2. *Clastic*. Examples are "made ground," concrete.

"Made ground" is a varied mass consisting of human exuviæ of every conceivable kind, mixed with more or less of soil or rock. In one place it may be entirely composed of fragments of manufactured articles, at another purely of natural rock. In the latter case its artificial character may not be at once realized, e.g. the material excavated from a well, spread out and overgrown with vegetation. But even though it has every appearance of being a natural formation, it differs from it in the very important character of being out of its natural place, not only as a whole, but in the relative position of its parts. Pieces of different strata have been mixed together, and the whole has been moved, in the particular case mentioned, against gravitation.

As natural deposits in some ways analogous, we may instance parts of the Glacial Drift, which consists, as a rule, of a mass of materials of varied size and origin, as in the case of made ground. Both deposits may have been moved great distances, or made of local materials. A mass of rock may be torn up by ice, and its ingredients mixed together without leaving any obvious

sign of disturbance, as, for example, in Middlesex, where, in some places, Glacial Drift is composed of transported London Clay, and since it rests on solid London Clay, it is not always separable from the undisturbed strata below. Such a state of affairs is similar to cases in which Man has turned over the ground without introducing any foreign element to call attention to the disturbance. In other cases the materials of the Glacial Drift are derived from afar, and exhibit a marked contrast to the rock on which they rest.

"Made ground" may be a flat deposit, relatively thin, or it may be heaped into mounds, in which form it sometimes resembles the moraines, kames, or eskers left by glaciers. In other cases it forms terraces in valleys, when it resembles in shape the gravel-terraces left by rivers. Instances of such terraces may be seen on the outskirts of Sheffield, where some of them are now cultivated as allotments.

Æolian. Examples of artificial æolian rocks are comparatively few. Where the waste products of some industry are in a state of fine division and come under the action of wind, they are formed into dunes similar to those of the seashore. Perhaps the best illustration is the sand derived

from the finely powdered banket of Johannesburg. After the gold has been extracted the tailings are dumped near by, and under the action of wind are rearranged into dunes.

If material churned up by Man, instead of being deposited on land, finds its way into a sea, river, or lake, whether by accident or design, it is sorted and spread out by water and forms a sedimentary rock, the human origin of which is only shown by the nature of the constituent fragments, or not at all if no fragments of extraneous substances have been introduced. Yet without human action the clay or sandbank formed would never have existed. Here the boundary between artificial and natural rock is breaking down, as always happens when we attempt to put natural processes and things into classes. From these remarks it appears that artificial clastic rocks can be divided into three groups :

(*a*) Those petrographically unlike anything in Nature, e.g. the waste from a chemical works.

(*b*) Those differing petrographically from naturally formed rocks in minor points only, such as (1) the state of attrition of the particles, e.g. the mounds of sand that has been used for polishing glass ; or (2) in the admixture of particles of artificial origin

with ordinary sand or clay, e.g. glass-dust in the mounds of sand just mentioned; or (3) in the presence of an occasional relic of Man, such as a fragment of pottery, which in a natural rock would correspond to a fossil.

(*c*) Rocks apparently entirely natural, yet owing their formation to human activities, e.g. masses of silt deposited through an artificial change in the position of a current of water.

3. *Metamorphic*. Examples: Brick, porcelain, cements, distilled oil-shale.

In the manufacture of bricks the clay from which they are made is heated to a temperature more or less high according to the kind of goods required. The chemical and mineralogical changes that occur in the clays treated in the kiln are very similar to those undergone by a clay during its metamorphosis by an igneous rock. We may therefore regard bricks, tiles, terra-cotta, earthenware, and porcelain as metamorphic rocks. Portland cement is similar to a metamorphosed, argillaceous limestone, and it, together with other cements and mortars, may be put in the metamorphic division. The shale from which paraffin has been distilled may also be placed here.

All these artificial products are similar

to thermo-metamorphic rocks, i.e. rocks altered by the heat and vapours generated by igneous intrusions. The other division, the dynamic metamorphic rocks, such as schists and gneiss, formed by earth movements on a large scale, do not seem to have any artificial representatives.

4. *Chemically formed.* Examples: Waste from various chemical works and from water-softening processes.

Here we may place such materials as the heaps of finely divided calcium carbonate precipitated from drinking-water by Clarke's water-softening process, and the heaps of calcium carbonate from the ammonia-soda process for making caustic soda and sodium carbonates. The chemical substances manufactured may themselves be regarded as man-made rocks or minerals.

A vast number of substances made by Man are never found in Nature. Not only are there the organic compounds produced in the laboratory (now more than 150,000 in number), which are strictly comparable to native minerals such as ozokerite, asphalt, or copal, but there are also inorganic substances which differ from minerals only in the fact that they owe their existence to the chemist instead of to Nature. An interesting case is that of ferrous sulphide, which

is a common reagent in the chemical laboratory, but in Nature is only known from meteorites.

A question will arise in many minds: do any of the products of human activities occur in sufficient quantity to be compared with masses of rock? The answer is that they do: the "made ground" on which a large town stands is of the same order of magnitude as a seam of coal, a stream of lava, or a marine beach. So also are the tip-heaps of many colliery districts or the slag-deposits of an iron-making centre. In other cases the artificial product is disseminated in small quantities, which, if brought together, would make up a very considerable mass. Take the case of glass, for example; hundreds of millions of tons have been made, but have been scattered over the earth in the form of small articles.

The most important use of slag is for road-metal. A new development is the introduction of tarred macadam, for which slag, being porous, is particularly useful. Some of the old tip-heaps are now being quarried for this purpose. Basic slag is by far the most easy to utilize. The slags from the acid-process weather into an earthy condition, and hitherto scarcely any use has been found for them. Basic slag, on the other

hand, besides the uses above mentioned, is also valuable as a phosphatic manure.

Cleveland slag has found important uses in the improvement of the Tees. The North and the South Gare Breakwaters, which project into the sea on the two sides of the estuary, are made of the slag. The North Gare is rather more than a mile long and the South Gare nearly $2\frac{1}{2}$ miles long. The two will contain about 5 million tons of slag. In addition, training walls extending for 20 miles along the Tees had used, by 1878, about $1\frac{1}{3}$ million tons. A great deal of land, about 2,433 acres, between high and low tides had been filled up with slag and built on. In spite of the quantity that has been used, an immense mass of slag remains to be disposed of and is tipped along the river between Stockton and Redcar. In some cases it is built up into terraces which at the highest point, opposite Grangetown Station, must be nearly 200 feet high. The total amount smelted, up to 1905, may be roughly estimated to have produced about 108 million tons of slag. In addition large quantities of ores other than Cleveland have been smelted in the district.

One of the largest accumulations of industrial waste is that covering the so-called

Black Country, i.e. the district between Birmingham and Wolverhampton. The boundary of course is not sharply defined and it includes small areas, e.g. between Short Heath and Walsall, relatively free from waste. These are counterbalanced, however, by patches lying outside the area. In a rectangle of exactly 3 square miles containing Bilston and part of Willenhall, there are 92 coal-shafts and 6 bore-holes, $3\frac{1}{3}$ miles of railway, $1\frac{1}{6}$ miles of canal, and 135 ponds. These figures give some idea of the remarkable appearance of the district. In places the waste-heaps have been levelled for building sites, but elsewhere the surface is extremely uneven, with ponds lying in the hollows; and the mass may be compared to the kettle-drift left by a glacier. The materials are, firstly, shale brought up the coal-shafts; secondly, slag from blast-furnaces; and thirdly, an endless variety of *débris*, such as chemical waste, broken bricks, the waste of all the varied industries carried on in South Staffordshire, together with the ashes and other rubbish thrown out of houses. Supposing the rubbish has an average thickness of 10 feet over the whole $22\frac{1}{3}$ square miles of area, the bulk of the mass will be $230\frac{1}{2}$ million cubic yards.

The other coal-fields offer similar deposits

to those of the Black Country, although nowhere continuous over such a large area. The total quantity of coal dug in the British Isles between 1500 and 1928 is roughly 16,166 million cubic yards. If we assume that a bulk of rock equal to half that of the coal has been brought out of the coal-pits, the rest being stowed below, then the contents of the various colliery-tips in the British Isles (we may almost say in Great Britain) is about 8,083 million cubic yards of compact rock. In the fragmentary form in which it is found in tips it will occupy about $2\frac{1}{5}$ times the bulk of the original rock, or 17,782 million cubic yards. This mass would cover an area of 10 square miles to the uniform depth of 1,722 feet.

Oil-shale is mined in a similar manner to coal, and, after being broken up into pieces as large as a man's fist, is passed into retorts, where it is subjected to a temperature of 1,800° F. The waste product amounts to about 70 or 75 per cent. by weight of the original rock, and is tipped into dumps ("bings"), which are usually 200 feet and occasionally 300 feet in height. The dumps of one of the seven firms, in 1918, covered some 22 acres to a depth of about 200 feet. Considerable quantities have been used by building contractors for filling voids, and

some has been used for footpaths and tennis-courts and for asphalt pavements.

The total output of oil-shale from 1873 to 1928, inclusive, was 117,835,301 tons, which at $1\frac{1}{5}$ cubic yards per ton would produce 141,402,362 cubic yards of waste, but probably the bulk is really a great deal more than this. The industry commenced in 1850, although there are no statistics until 1873, so that an inclusive estimate of 150 million cubic yards of baked fragmental waste for the whole period is not excessive.

The old Leblanc or black-ash process of making carbonate of soda and other chemicals produced a great mass of waste, which was dumped near the works. For many years the heap gives off a yellow liquid, which pollutes the streams and canals. It is decomposed even by the carbon dioxide of the atmosphere, but still more readily by the air of drains, or by the acid waste liquors from the works, and gives off sulphuretted hydrogen. The nuisance has now been abated, for sulphur is extracted from the fresh waste by Chance's process.

The Leblanc process is giving way before the ammonia-soda and electrolytic processes, which produce waste of another kind to be presently referred to. So extensively, how-

ever, has the Leblanc process been carried on in the past that the old waste-heaps are characteristic of the scenery around Widnes, St. Helens, and other centres of the industry. Mr. E. Rhodes estimated that, in 1909, there were 500 acres of land at Widnes alone, heaped with the waste to the average height of 12 feet, and containing some 10 million tons of material. This, when fresh, would contain 1½ million tons of sulphur. The quantity of sulphuretted hydrogen that formerly escaped into the atmosphere may be imagined from the fact that 31,350 tons of sulphur were recovered from waste in 1892 alone. A great part of this sulphur would formerly have been oxidized from sulphuretted hydrogen into sulphuric acid, which would have attacked crops, mortar in houses, and a host of other things.

The waste from the ammonia-soda process is of a totally different kind. The process was commenced by Solvay about 1866, and was introduced into England in 1874, when the first works was erected at Northwich, Cheshire. G. Martin and others estimate (1916) the present output of Cheshire alone at over 500,000 tons of sodium carbonate annually. The material forming the dumps is mainly calcium carbonate and in some places is used for making Portland Cement.

Although metals and alloys occur rarely as minerals they never form rock-masses and the metals we see everywhere are made by Man. Many metals have but a temporary existence. Iron, for instance, readily rusts and disappears when exposed to weather, unless special precautions are taken to preserve it. Copper, similarly, will turn into verdegris; lead is more resistant because the weathered surface protects the metal underneath. Silver rapidly tarnishes, especially if there are traces of sulphurous gases in the atmosphere, as near towns. Tin is amongst the most stable of the metals. Gold and the platinum metals alone permanently resist weathering agents, but are all rare substances. It follows that although metallurgists have made enormous masses of metals since they began their work, their products are not permanent. As much iron was produced in the twenty-five years ending 1911 as in all the previous centuries, so that the volume of iron is growing rapidly. But only relics survive of that made in ancient times; the remainder has become rust and been disseminated through the soil, whence it will sooner or later find its way into the rivers and be mingled with ordinary sediments. Iron can be preserved by painting, or by embedding it in concrete: if neglected it perishes.

From the petrological point of view metals are the most ultrabasic of rocks. It is probable that, although almost unknown in the earth's crust, they nevertheless form the central core of the earth.

Concrete is an artificial breccia or conglomerate, according as it is made of angular fragments or round pebbles embedded in lime or cement. The "aggregate," as the fragments are called, is of varied character; pieces of brick, stone-quarry *débris*, and shingle from either the seashore or gravel-pits being the commonest constituents. In concrete it is necessary that the lime or cement should be sufficient to fill up the interstices of the sand and the combined lime and sand must completely fill the voids between the stones of the aggregate. In good concrete we should have one part of cement and three of sand mixed with twelve parts of gravel or eight parts of broken stone.

Although concrete seems to have been used abroad in very ancient times it was not until 1832 that it began to receive attention in England. Then came cases of failure due to bad engineering, which brought concrete into discredit for a time; but it is now being used on an increasingly great scale, especially in the form of concrete reinforced with iron rods, which add considerably to its strength.

The amount of concrete in existence must be very great, but there are no figures by which it can be estimated. The Gatun locks on the Panama Canal alone contain over 2 million cubic yards, and all the Panama locks together contain $4\frac{1}{2}$ million cubic yards. A considerable proportion of the Portland cement output is used up in making concrete, of which it forms from one-sixteenth to one-twelfth, and the world's output of Portland cement in 1903 was from 7 to 8 million tons, while in 1908 the United States alone made 8,651,843 tons of cement.

Cements are of two kinds: natural, and artificially mixed. The former are made from septaria or argillaceous limestones, in which the clay and limestone are present in the right proportions to form cement; the second class are made by mixing the necessary constituents. In making artificial cements there is a loss of 25 per cent. of the rock.

The bulk of the natural cement is obtained from the Lias, a part of which consists of layers of argillaceous limestone separated by beds of shale or clay. Each layer of stone is separated, cleaned from shale and stored by itself. The layers vary slightly in composition, but do not differ much from the theoretical analysis of cement. It is

easy by mixing them with shale and with one another to obtain the right composition. The rocks are ground to powder, burnt in a kiln to semi-fusion, and the clinker is ground to an extremely fine powder and is then ready for use.

Portland cement was first made in England by Joseph Aspdin in 1824. It is the most important of the artificial cements, and is obtained by burning to semi-fusion a mixture of approximately three parts of calcium carbonate, and one each of silica, alumina, and ferric oxide. The raw materials used are limestones and clays.

Now that it is possible to use the alkali waste both from the ammonia-soda and the Leblanc processes, after recovering the sulphur in the latter case by Chance's method, there is a prospect of the eventful utilization of the old alkali tip-heaps.

From our point of view bricks can be grouped into two classes: sun-dried and burnt. The former are merely clay hardened in the sun, and in a humid climate may be expected to revert to the mud from which they were made, although their use has recently been advocated in England. Burnt bricks, however, have undergone a chemical change, similar to that undergone by clays that have been metamorphosed by

an igneous mass, and bricks are artificial metamorphic rocks.

In countries where building-stone is rare or absent, brick-making is of great antiquity. Professor Banks, of Chicago, says that bricks were made in Mesopotamia ten thousand years ago, but these were merely dried in the sun. The earliest burnt bricks were made about 4500 B.C. In dry climates sun-dried bricks last a long time, and they are still being made in Spain, India, and other countries; but burnt bricks are far more permanent—in fact, when of good quality they seem to outlast almost all stone-work, unless they are accidentally broken.

The earliest notices of brick-work in England relate to Cambridge in 1449, to London in 1453, and to Oxford in 1460. In Nottingham the first brick-built house was erected in 1615 and was pulled down about 1910. Previously, in Nottingham, bricks had been used for chimneys and filling in between the timbers. Doubtless lath and plaster buildings continued for a long time after the introduction of bricks, in fact such buildings are not uncommon even now in country districts.

Many bricks of the Tudor period were probably imported from Holland. After the

Great Fire of London bricks were used generally for rebuilding the city. The tax on bricks, lasting from 1784 to 1850, frequently caused brick-work to be replaced by stucco for outer walls. In the last thirty years of the nineteenth century the invention of the machine-made brick caused a great development in building, which lasted until the Transvaal war, when the demand for bricks fell off greatly.

We have no data by which to estimate the output of bricks and tiles in Britain, before the eighteenth century. Such of the Roman tiles as escaped damage were incorporated in new buildings, although it is probable that many so-called Roman tiles are of Saxon or Norman origin. The earlier bricks have in the course of time been broken up and incorporated with "made ground," except in a few buildings of antiquarian interest from their rarity.

The largest centre of brick-making at the present time is at Fletton, near Peterborough. In 1887 the industry was in its infancy; in 1890 about 50 million, in 1900 about 500 million, and in 1903 about 800 million bricks were made. Apart from the suitability of the clay, this enormous output is due to the proximity of a main railway-line to London, which has enabled

Peterborough to destroy many of the small brick-works in other parts of the country. The coming of railways, in fact, has had a double effect on the production of bricks; it has concentrated the output into a few large centres supplying most of the country, and it has increased the total production by offering facilities for distribution. When only locally made bricks of inferior quality were available, building-stone was used for many purposes for which suitable bricks are now easily obtained.

For the output of recent years we have the Census of Production, which gives the number of bricks made in 1907 as 4,794,739,000. They represent the burning of about 19¼ million cubic yards of clay.

A Committee appointed by the Ministry of Reconstruction put the annual output for the three years 1911–13 at 2,805,748,000 bricks, which would require 11¼ million cubic yards of clay annually. In 1917 the approximate output was 1,052,246,000 bricks. The reduced output was of course due to the war, but also in part to the fact that only bricks fit for house-building were counted.

In 1907 the output of roofing and street-paving tiles was 308,585,000. It has been found that 6,000 cubic yards of clay will

produce 4,600,000 tiles, in addition to 400,000 broken or unsaleable ones. The year's output therefore means the burning of 4 million cubic yards of clay.

Bricks may resist ordinary agents of denudation for an indefinite time. Man, however, has produced some extraordinary agents, notably the gases that mingle with the air in manufacturing towns, where the greater part of the brick-work is to be found. In ordinary air the proportion of carbon dioxide is 0·030 per cent.; but Dr. Angus Smith found that Manchester air during fogs contained as much as 0·0679 per cent. This gas plays an important part in the decay of bricks containing calcium carbonate. Dry air will not attack bricks, but the carbon dioxide dissolving in rain-water forms with the calcium carbonate the soluble bicarbonate, which is then washed away. The most powerful agent added to the air is, however, sulphuric acid. This is formed by the burning of coal, which always contains some iron sulphide ("brasses"). The air of Lille was found by A. Ladureau to contain 0·00018 per cent. by volume of sulphur dioxide. This gas is quickly oxidized and, dissolving in rain or fog as sulphuric acid, attacks anything within its reach. The smooth outer skin

of a brick is a great protection, and if the corners of a brick become broken, rain-water is able to attack the more porous and less fully burnt interior. Moreover, the wet broken surface is frozen in winter and the surface flaked off. Soot also helps in the destruction of the bricks to which it clings. In some towns the bricks may be seen falling into a granular powder, although in the same district other bricks, e.g. the blue bricks of the railway-bridges, remain solid. But although a brick may fall to brick-dust it does not return to clay, for the burning has altered the clay chemically, and brick-dust will not puddle. Whether brick will return to clay in the course of ages it is impossible to say, but fragments of Roman tiles are not uncommonly dug up in the same condition as when they were made, say, 1,500 years ago, and the Assyrian records made on bricks are unaltered after a lapse of four thousand years. Man appears therefore to have made a permanent record of himself, not in buildings, which are temporary, but in brick-dust—a new substance of his own creation. Whether this is really permanent in the true sense of the word is doubtful, for it is not unlikely that in a geological period the brick may undergo hydration and return to clay.

The oldest house in England built entirely of brick is Little Wenham Hall, Suffolk, built in 1281. Since brick buildings have a comparatively brief existence, what becomes of the materials of which they are composed? Old buildings soon fall into ruins if neglected, but frequently they are pulled down and the bricks carted away, either because the lease has expired, or the building has become insanitary, or it is to be replaced by some other building, or it has been damaged by fire. As a rule about half of the bricks are fit to be used again, but the other half will be too much damaged and these will be broken up for concrete, or used for the foundations of roads as "hardcore." A good deal of broken brick is simply left lying about waste land, or dumped into old pits. Sooner or later the rubbish left on waste land has to be cleared up, and so the broken bricks will eventually be dealt with in one of the ways mentioned. In some cases it is crushed to powder to spread over garden paths. Tiles and drain-pipes suffer the same fate as bricks.

In a recent discussion it was stated that the average life of a Scotch tenement is one hundred and fifty years, and of an English cottage about sixty years, before they fall to pieces.

It is customary to use inferior bricks for the inside of the walls and better bricks for the outside: and when a building is demolished, the bricks used on the outside will on the average be sound enough for use on the inside of the new building erected on the site, while new bricks will be used for the outside.

To estimate the bulk of brick-work in the country we require to know, (1) the number of each kind of brick building, (2) the average quantity of brick-work in each kind of building.

The Census returns for 1911 give us the numbers of buildings in England and Wales classified as (1) inhabited houses, 7,141,781, and uninhabited 408,652, building, 38,178; (2) places of worship, 49,970; (3) government and municipal buildings, 10,533; (4) shops, 172,665; (5) offices, 28,752; (6) warehouses, workshops, factories, 139,977; (7) theatres and other places of amusement, 3,050. The classification adopted in 1921 is less satisfactory for our purpose.

Not all these buildings are built of brick; the figures include stone buildings also, and, on the other hand, they do not include such buildings as stables, barns, and other outbuildings. All the brick-work used in railways and other engineering structures

and in walls round gardens, yards, fields, parks, etc., is omitted. In many parts of England and Wales, particularly in rural districts and ancient towns, stone buildings still form a large part of the whole, and in some districts one sees a good many cottages built of wood. The proportion, however, is very much less than it used to be, and is probably still diminishing. Except for public buildings, bricks become more and more universal. On the whole, brick greatly predominates over stone in buildings, even public ones.

The additions and subtractions to be made to the Census figures, when separating the brick-work from the stone-work, are large, but perhaps roughly neutralize one another. No more than a rough approximation to the bulk of brick-work is possible at present, but even an approximation enables us to realize the important part taken by brick-work in modifying the surface of the earth. We shall therefore set off the stone buildings against the walls and engineering structures built of brick and assume that all the buildings numbered by the Census are of brick.

Estimates of the number of bricks in a small house vary from 20,000 to 30,000. The lower figure may be taken as the number

in a workman's house, and 25,000 as the average for all kinds of dwelling-houses. On these figures the total of bricks in dwelling-houses in England and Wales at the date of the 1911 Census was 189,715,275,000; the houses being built at the time are included because they would be completed soon afterwards. The bricks would have a volume of approximately $355\frac{1}{3}$ million cubic yards, or 480,292,000 cubic yards of brick-work, produced by the burning of about 759 million cubic yards of clay.

It has not been found possible to estimate the brick-work in other types of buildings, but from data given in the *British Clay-worker* it appears that large institutions average about 10,000 bricks per inhabitant. The number of people living in institutions in England and Wales the night of the 1911 Census was 573,338; in barracks, 135,755; a total of 709,093. We may therefore estimate the brick-work in institutions at 17,951,000 cubic yards. The bulk of brick-work in other buildings can only be guessed at. It would, however, certainly be more than 2 million cubic yards, and so we estimate the total standing brick-work in England and Wales in 1911 as of the order of 500 million cubic yards.

On our assumption that the average life

of brick-work is sixty years, the number of buildings destroyed in 1861 would be the same as the total number standing in 1801. Similarly in 1871 the number of buildings existing in 1811 would be destroyed. On our further assumption that half the brick-work is fit for use a second time, the amount destroyed in 1861 would be half the total bulk standing in 1801.

It may be objected with truth that public buildings last longer than sixty years. On the other hand shops and offices have, on the average, a shorter life than houses, for they are frequently pulled down before they have decayed, and improved buildings erected in their stead. On the whole, therefore, we may regard the sixty years of average life as applying to all brick-work in England and Wales.

A graph has been constructed on the assumption that the amount of brick-work destroyed in any year is half the quantity standing sixty years previously. Thus the bulk of brick-work standing in 1801 being 107,557,613 cubic yards (calculated from Census returns), the bulk destroyed in 1861 will be 53,778,806 cubic yards. We find that the brick-work destroyed during the sixty years from 1861 to 1911 was 4,575 million cubic yards. All this material has

passed into "made ground," concrete, brick-dust, etc.

Although the brick-work used in the railways is included in the estimate given above, as a set-off against stone-work, it can be separately estimated and amounts to 140 million cubic yards.

An immense mass of brick-work has been used in sewers. The main sewers of London contain about 700 million bricks, made from about 2,800,000 cubic yards of clay.

As a rule the manufacture of stoneware pipes is carried on in connexion with a brick or terra-cotta works, for the pipes are usually made of clay scarps, shavings and cuttings, with the addition of bad or broken ware, "saggers," tiles, old fire-bricks, or linings from kilns.

Earthenware pipes for sewers and house-drains were not generally used in England until about 1848, when a sudden demand arose. Previously they were made of rough stone, unevenly laid, and soon became choked. Rugby was one of the first towns to be completely drained by tubular earthenware drains. However, unglazed earthenware pipes found at Chester are believed to have been laid by the Romans, and the Babylonians used similar ware.

When made from raw material a suitable

mixture contains from 30 to 40 per cent. of fat (sticky) clay mixed with a more open clay. A considerable part of the mixture consists of broken and burnt pottery, ground until it will pass through a sieve having, say, twelve or twenty-four meshes to the inch. The "grog," as this broken ware is called, may rise to as much as 50 per cent. when very "fat" clays are used, but may be very much less in other cases.

According to Fream, the distance apart of drains in arable land varies from 15 to 60 feet; 21 feet being an ordinary distance on heavy land. Taking 33 feet as the mean distance apart, there will be $\frac{1}{4}$ mile of drains per acre. Supposing the pipes to have a diameter of $2\frac{1}{2}$ inches and a thickness of $\frac{1}{2}$ inch, they would contain $\frac{3}{5}$ of a cubic yard of earthenware; or 384·1 cubic yards per square mile.

Estimates were drawn up by the Ministry of Reconstruction of the quantity of materials required in the erection of 300,000 cottages, each containing a living-room, scullery, larder, coal store, w.c., and three bedrooms. The total of stone-ware required would weigh approximately 319,000 tons (weight after being burnt). The estimates did not mention pipes more than 9 inches in diameter, as the local authorities are responsible for

the provision of main drainage, where not already laid down. Inquiries indicate that about 20 per cent. additional stone-ware is required for pipes over 9 inches wide, and so the 300,000 houses will need 383,000 tons of stone-ware including these additional pipes. The total stone-ware for these houses represents the burning of 421,000 tons of clay, or, at 25 cwt. per cubic yard, of 336,800 cubic yards. In the manufacture about 478,750 tons of coal, producing at 5 per cent. about 24,000 tons of ashes, would be burnt, and about 3,850 tons of salt would be used for glazing the ware.

Inquiries show that the quantity of stone-ware mentioned in the estimates is above that actually used in some industrial districts for working-men's cottages. The figures will, however, serve as figures for the average house with the addition of the street drains. The 7,588,611 houses of the 1911 Census represent, therefore, the burning of about 8½ million cubic yards of clay.

We have still to consider the tiles used in houses. Probably not more than 5 per cent. of houses have tiled roofs, and this proportion of the houses of the Census would contain about 1,147,000 cubic yards of burnt clay, while the whole of the houses would contain paving-tiles made from 175,000

cubic yards of clay. In addition a comparatively small amount of clay is represented by the ridge-tiles.

We may now add up the quantities of clay burnt to make up the houses of the Census of England and Wales for 1911, and we find that the total is approximately $768\frac{3}{4}$ million cubic yards. This is the amount of clay contained in the bricks, tiles, etc., in existing buildings; that used in bygone times and now destroyed is additional.

It is convenient to refer in this place to the quantities of slates required in houses, although slate is a natural and not an artificial material. On the assumption that roofing-slates have an average thickness of $\frac{1}{4}$ inch, 150,000 small houses require 228,730 cubic yards of slate. Assuming that 95 per cent. of the houses of England and Wales are roofed with slates, these would have, in 1911, a volume of approximately $38\frac{1}{4}$ million cubic yards.

In the previous chapter an account is given of "made ground": that accumulation of rubbish which is Man's most permanent memorial. The cities of the ancient world are now represented for the most part by mounds, though masonry also is found in a good many cases. Some of the buildings, such as the Great Pyramid, have

become famous as colossal engineering works. The mounds representing the sites of towns are sometimes mere accumulations of rubbish, but in many cases they have been deliberately heaped up as foundations for the buildings.

In Great Britain also there are relics of ancient man in the form of mounds. Barrows and tumuli are familiar objects in many parts of the country, but mounds of an unusual type are found in Essex, where they are called "Red Hills." They are deposits of red burnt earth or clay, 3 to 6 feet thick, and form patches or low mounds, often a few acres in extent. They stand on the alluvial marsh clay, and on the banks of the estuaries of the Colne, Crouch, and Blackwater Rivers alone they have been estimated at upwards of 240 in number. According to Chas. Dawson, in the *Antiquary*, the mounds consist principally of red burnt earth, occasionally mixed with wood, ashes, or slag, and containing fragments of pottery. They are supposed to have been accumulated during the Late Celtic period, before the Roman occupation. It is suggested that they are ballast heaps discharged from ships sailing from distant pottery centres and taking clay on their voyages.

CHAPTER VII

ALTERATIONS OF THE SEACOAST

OSCILLATORY movements have taken place along the coast-line of the British Isles, and there is good geological evidence that the latest movement, as regards England and Wales, was a submergence of 60 feet. That this was in progress so late as Neolithic times is shown by the discovery of stone implements and bone needles of that age on submerged and buried land-surfaces at various places, as at Barry Dock near Cardiff, and at Southampton, and exposed during excavations. Clement Reid, in evidence before the Royal Commission on Coast Erosion and Afforestation, said: "When the sea stood at a level 60 feet lower than now, most of our coast was fringed by a belt of low ground, extending out approximately to what is now the ten-fathom line. On the landward side of this belt was, and in many places still is, a steep grassy slope, representing the position of a still more ancient line of cliff, the face of which has

been hidden by rubbish washed from the slope above. The south and east coast of England, at the period with which we are dealing, must have been utterly unlike what we now see. Instead of bold cliffs, there was this wide coastal plain, like the plain which still extends for many miles west of Brighton, reaching a width of 8 miles at Selsey Bill. About 4,000 years ago a fairly rapid, but intermittent subsidence of the land, or rise of the sea set in; we do not yet know which it was, but for practical purposes the effect is the same. This rise of the sea-level flooded a great part of the coastal plain and brought the waves within striking distance of the rising land behind. It also submerged the lower part of all our valleys, turning them into winding sea-locks, or fjords, which penetrated far into the land."

There is no reason to suppose that submergence or emergence are now proceeding, except possibly in Northumberland and Durham. Reid thought "the rise of the sea-level may have been completed about 3,500 years ago."

The best natural protection from erosion by the sea is the shingle and sand accumulated round the coast-line. Beach material is practically all derived from the land, mainly by the erosion of cliffs, although in

exceptional storms a little may come up from beneath low-water level. Materials travel along the shore in definite directions, but may be arrested by headlands and rivers, or by artificial works such as groynes, harbours, and piers. The direction is usually that of the prevailing winds, due to the waves, which are governed by winds.

Since almost all beach material is derived from erosion of land, the supply is not inexhaustible; and beach material should not be interfered with where it protects the coast. As shingle becomes worn away, it is replaced by erosion at some other part of the coast, and it follows that, if coast protection became nearly universal, shingle would wear out and disappear, thus bringing about the necessity for further protection. In certain cases shingle may be removed with advantage, e.g. near harbours or estuaries, which might be blocked. Danger from erosion may also follow quarrying or dredging on the foreshore and beneath low-water mark, where the rock or loose material acts as a protection to the coast.

The following case described by Mr. Hansford Worth[1] affords an illustration of the

[1] Most of the information in this chapter is from the Report of the Royal Commission on Coast Erosion and Afforestation.

danger of removing shingle. South of Street Head, on the Devon coast, there is a beach 5 miles long, not replenished from local sources. In 1896 permission was given to dredge shingle and other materials from the foreshore opposite Hallsands, and from 1897 to 1901 an estimated quantity of 650,000 tons was removed, after which the licence was cancelled. Up to this time there had been no erosion, but from 1901 to 1904 many houses, sea-walls, and a road were washed away, the beach having fallen on an average 12 feet and in places as much as 19 feet.

It does not seem possible to estimate the amount of erosion caused, in the past, by the removal of shingle. Before the time of Telford much shingle was used on the coast-roads, for which purpose it was carried also to inland towns for centuries. The most serious case of erosion in this country, that of the Holderness coast, which has lost 115 square miles since 55 B.C., is considered to be partly due to this cause. In addition to shingle, much beach-material has been taken away for marling agricultural land. Even after more suitable road-stone had replaced shingle, the pebbles still continued to be collected for concrete and other purposes, e.g. large quantities of flint-pebbles

have been removed and ground to the finest powder for use in the manufacture of porcelain and stone-tiles. Others are used in flint-mills. On the coast of Normandy, where the flint-pebbles are particularly in demand on account of their purity, it is estimated that 121,000 metric tons were removed in 1907. To yield this quantity annually it is necessary that two million cubic metres of chalk should be destroyed by the sea, and Mr. Cloez estimates that this is about the annual amount of denudation of the chalk cliffs. It appears therefore that the removal of flints on the Normandy coast is responsible for the denudation of the chalk cliffs there, for if they were left alone they would protect the cliffs from erosion.

An allied cause of erosion is the quarrying of stone in the cliffs. This cause is said to have been in action at Kinaird, Aberdeenshire, and also east and west of Lyme Regis, Dorset.

The usual effect of protecting the coast in one place is to initiate or promote erosion in a neighbouring part, generally by stopping the flow of material along the shore. Erosion has occurred, in consequence of defence works, near Bridlington, Sheringham, Cromer, Corton near Lowestoft, Hastings,

Bexhill, Eastbourne, Brighton, Hove, Blackpool, and Silloth, while the places named, amongst many others, have all been protected and in many cases groynes and piers have resulted in a gain of land. A salient pier at a harbour entrance causes an accumulation of beach-materials to windward and leaves the shore to leeward subject to erosion, necessitating protection there. Sea-walls, unless properly constructed, are agents of their own destruction, for if they are not well designed, the waves that break against them tend, on recoiling, to scoop out beach-material at their feet. If not held in place by groynes, or other means, the walls are undermined.

Erosion is sometimes greatly retarded by the draining of the cliffs, and the consequent prevention of landslips. This has been carried out at Scarborough, Frinton in Essex, and Shorncliffe.

Another method of protection is to encourage the growth of marram grass, and some other plants, on sand-dunes. The plants bind the loose sand together and prevent it from being blown inland; so offering a barrier to the sea and at the same time keeping the sand from overwhelming the land behind. The method has been adopted near Wells, and also between Winterton and

Happisburgh, all in Norfolk; also at St. Andrews, in Scotland. At Shoreham, Sussex, a hedge of tamarisk protects a shingle-beach from erosion. The mudflat between Hurst Castle and Southampton is covered by three species of Rice-grass (*Spartina*), which helps to reclaim it. Although the grasses grew here naturally, one if not two species are not natives of Britain and must have been introduced by Man.

There is no clear line of separation between works for coast protection and works for reclamation from the sea. On the whole Man is adding to the area of the country, for the lands reclaimed are considerably larger than those lost through his activities.

According to the third Report (1911) of the Commission already cited, it appears that, within a period of about thirty-five years, an area of 4,692 acres has been lost to the sea in England and Wales, and 35,444 acres gained; a nett gain of 30,752 acres. Scotland lost 815 acres and gained 4,704 acres, a nett gain of 3,889.

The land gained from the sea is situated almost entirely in tidal estuaries, and, to a very great extent, is due to the deposition of silt, whereas the losses are chiefly on the open coast. Gains by deposition of silt are not always intentional, but may be caused

accidentally by interference with natural conditions.

Cases where the foreshore has been filled up by direct action of Man are relatively few. This has happened at Workington, where the slag from the iron-furnaces is not only filling up large areas of foreshore, but is in part drifted along the coast, and, mixed with natural shingle, is causing accretion on the south coast of Walney Island.

The most striking case of reclamation by direct filling up of the foreshore is probably to be found in the Tees estuary. Slag from the Middlesbrough iron-furnaces was taken in vessels and dumped on the boundaries of the area to be reclaimed. When the surface of the slag-tips had risen above high-water mark, railways were laid down along them and the slag was then shot into the enclosed area until it was filled up. Some 4,270 acres have been filled or are in process of being filled up.

The River Humber, which contains more silt than any other English river, is caused to deposit its burden by the erection of obstacles, such as fences. This process has been carried on since the time of Charles II, and near Sunk Island alone a total of about 7,000 acres of tidal mud has been converted into rich arable land. Probably not more

than another 1,600 acres can be reclaimed without injury to navigation.

In the Wash about 2,200 acres have been reclaimed in the King's Lynn district since 1857. It has been found that not more than 250 acres can be dealt with at one time, and that it takes from twenty to thirty years for the warp (silt) to deposit over the area before it becomes land fit to enclose. By that time its surface should be nearly level with spring-tide mark, otherwise it is practically useless.

On the Mersey, about 1,230 acres of tidal lands have been reclaimed during the last century, and now form the site of Liverpool Docks. About 550 acres remain to be reclaimed and are intended to be used for more dock extensions. It is thought undesirable to reclaim more land above Liverpool as the volume of water necessary to scour the channel would be dangerously reduced.

From the Ribble, more particularly near Preston, about 7,400 acres were reclaimed in the last century. In Morecambe Bay the sea has broken into a tract of land that had been reclaimed. It is stated that 35 square miles of foreshore are suitable for reclamation. The embankments of the Furness Railway, between Grange and Arn-

side, and at Holker, between Cartmel and Ulverston, have reclaimed hundreds of acres, but the area is covered with sand and of little value.

Holland offers the most striking instances of land reclamation. As early as the twelfth century the Dutch were renowned for their skill in coastal defence. In 1277 the country near the mouth of the Ems was inundated, and for more than two centuries the flooded land remained a swamp. The struggle with the sea is still proceeding; since the sixteenth century over 12,500 acres on the coast of Friesland, and about 57,000 acres on the coast of Groningen, have been reclaimed. Reclamations at the mouths of the Maas and Scheldt have increased the size of Holland by about 250,000 acres of agricultural land, since the twelfth century.

Holland, within its area of 12,648 square miles, contains about 1,600 miles of sea-dykes. Until the sixteenth century the sand-dunes were continually changing their positions and shapes, but planting with grasses was then commenced, the principal ones being *Ammophila arenaria* (helm-grass) and *Triticum junceum*. The dunes are now almost stationary everywhere. This dune-barrier, on which the existence of Holland depends, is in many places from one to

three miles wide and in some places attains a height of 130 feet.

In 1900 the mercantile docks in the United Kingdom numbered 230, with a tidal-water surface of 2,750 acres, besides 388 tidal and other basins. There were also 210 acres of timber pools and 279 graving docks. In 1903 Mr. J. C. Hawkshaw stated that wet docks (i.e. docks with a lock or tidal basin closed by gates) were almost confined to this country and neighbouring coasts of Europe. The Mersey docks had quays equal to two-thirds the length of those of the rest of the world.

In many cases the materials excavated are superficial deposits, such as peat and alluvium. The Tilbury Docks, for example, were excavated mainly in these deposits and in gravel, although hard chalk was found below the gravel. The total excavation was 4½ million cubic yards of material, all used up in making the quays, which are in general 12 feet above the original surface level.

Liverpool was an important harbour even in 1550, and in 1565 there were 15 vessels of 268 tons burden trading there. The original port was a narrow creek, called the Pool, which extended inland from the site of the present Custom House for about a mile in a north-easterly direction along what

is now Paradise Street. Vessels were loaded and discharged by boats in the river, or by grounding them on the banks of the creek and using carts at low water. In 1708, during Queen Anne's reign, the construction of a dock of 4 acres at the mouth of the old Pool was authorized. Both dock and creek have long since been filled in and built over, and the site is only indicated now by a depression.

For more than 6 miles, and for a width of from 700 to 2,200 feet, the foreshore between high and low water, on the Lancashire side, has been enclosed by a sea-wall, except at the entrances to docks. The earlier docks were made abreast of the original one mentioned above, to the north and the south, and included the Salthouse, George's and Prince's group. George's Dock was made under the Act of 1761 and has now been filled up and built over. George's and Seacombe Ferry Basins were filled up to make the landing-stage. New extensions of the docks were begun in 1873. North of the Canada Dock the excavations were chiefly in boulder clay overlain by a thin coating of sand. The total excavation was about 6 million cubic yards. Much brick clay was obtained, and over 30 million bricks were made from it and used in the buildings. To the south

of Rimrose Brook new extensions were also made, the first being the Herculaneum Dock, and here the slope of a hill, rising to 70 feet above the quay level, had to be excavated. Over a million cubic yards of New Red Sandstone were blasted and deposited 10 miles beyond the river-bar. At Tranmere, Birkenhead, the outer basin to the growing docks required the excavation of 80,000 cubic yards of sandstone and 520,000 cubic yards of clay and sand.

Although so much material has been excavated in making docks, the nett result is the reclamation of land. For the most part docks replace mudflats, covered by water at high tide and neither land nor sea. This debatable territory is resolved partly into land and partly into permanent water (the actual dock), and the boundary of the coast is sharply defined by walls, at the outer margin of the former foreshore.

Reclamations of land are confined to shallow water. An important result of engineering operations along the coast is the sharpening of the foreshore. By comparison of the Ordnance Surveys of different dates, Colonel Holland found a nett loss of foreshore of 31,232 acres in England and Wales; 8,371 acres in Scotland; and 7,471

acres in Ireland—a total loss for the British Isles of 47,074 acres. This loss is estimated by comparing the low-water marks of two surveys, taken at an interval of about thirty-five years. The reduction of foreshore is caused, on the one hand by the filling up of shallow water areas when reclaiming land, and on the other by dredging shallow waters in the vicinity of ports. The effect is to steepen the gradient of the foreshore, and one result of this is to minimize any change in the coast-line due to an alteration of sea-level.

An interesting biological result of the reduction of foreshore is the increased "struggle for existence" that must follow amongst the animals and plants that live between high- and low-water marks. Investigation would probably show a great reduction in individuals, or even the total extermination of some species, and modifications in the survivors.

Dredging has two aspects: if it is carried out in the sea it directly assists denudation by deepening shallow water, but if in a river and if the material is dumped on the land, dredging may appear to oppose denudation by replacing on land material in transit to the sea. It is, however, more usual to drop the dredged material into deep water,

in which case it is definitely lost to the coastal shelf.

The effects of dredging are temporary, for new sediment is continually being swept in to replace that removed; nevertheless, dredged material is placed in positions other than those intended by Nature, and there is human interference to that extent. Also dredging encourages the deposition of material to replace that removed.

The quantities of soft rocks dredged are enormous, but it is only since 1890 that the invention of powerful machines has enabled the operation to be carried on at anything approaching the present rate.

In the six years 1897–1903 there were dredged from the Mississippi 6,129,000 cubic yards. A contract was made in 1904 to remove 42½ million cubic yards of sand and gravel from New York Harbour, in order to open the Ambrose Channel. The channel is 2,000 feet wide and 40 feet deep, and the work was performed by two dredgers. Prior to 1898 the Government had removed 32½ million cubic yards. In 1899 a contract was made and carried out for making a channel 1,200 feet wide and 40 feet deep at mean low tide on the east side of the harbour; and 22 million cubic yards of sand and mud were removed.

The larger of two dredgers used in the Mersey removed 2,000,000 cubic yards in 1898. It was stated by Mr. Haupt in 1911 that up to that time 130 million tons had been dredged from the Mersey bar and channel (equal to about 106 million cubic yards).

In the case of the Clyde all dredgings obtained up to 1862 were used to reclaim land; after that date most of the material was taken out to sea. Between 1844 and 1879 dredging amounted to about 23 million cubic yards. It was estimated that, of 992,354 cubic yards dredged in 1872, about 299,000 cubic yards were brought down by the river and sewers, and 693,000 cubic yards was new material produced by deepening and widening the harbour and river.

Up to 1885, the total amount dredged from the River Tees was 15,130,000 cubic yards, while more than 124,000 cubic yards of rock was removed by blasting. The river has also been straightened between Stockton and the sea by cutting through the meanders. One of these cuttings, that of Portrock, is 1,100 yards long by 250 yards wide and 16 feet deep. For 7 miles above and 13 miles below Middlesbrough the river is kept in place by training-walls, which during the period 1859–1877 absorbed 1,356,628 tons of iron-slag.

CHAPTER VIII

THE CIRCULATION OF WATER

CIRCULATING water is one of the most potent of all Geological Agents. In this chapter we shall discuss Man's interference with the flow of water, whether in amount or in direction, and whether above or beneath the surface of the ground. A fundamental alteration in the circulation of water is affected when the rainfall is modified, but it seems desirable to discuss this alteration in the chapter on Climate, and here we deal only with water flowing on or under the land.

The first Act of Parliament authorizing the expenditure of public money for land-drainage was passed in 1840, though it remained inoperative and another Act was passed in 1846. Previous to that date such drainage as was done was undertaken by tenants, as a rule, and after the lapse of twelve or fourteen years it ceased to be of any value, because the drain-pipes were laid only one or two feet below the surface,

and, even if they remained unbroken, they became choked with roots.

Mr. Bailey Denton estimated, in 1856, that Great Britain contained 22,890,000 acres of wet lands requiring drainage, while the area of the land permanently drained was only 1,365,000 acres. Improved drainage and deeper ploughing, both introduced between 1840 and 1860, have caused the disappearance of many a perennial small stream, hedgerow ditch, or burn; and have also reduced the proportion of rainfall available for percolation, thereby diminishing springs and underground water supplies.

By improving land-drainage the speed with which the rainfall reaches the sea is increased, thereby rendering the climate drier than before, and even causing droughts. Streams, both large and small, are straightened, in part to gain land, since a straight course occupies less space than does a tortuous one, in part to prevent floods by increasing the velocity of the stream, and in other cases to render them more easily navigable.

Mr. G. W. Lamplugh has pointed out that when the population of a country becomes settled, streams have to be "tamed." They cannot be permitted to flow in variable and winding courses and to overflow their banks

in wet weather; stabilized channels are therefore made, reduced in width and rendered deeper and more gutter-like than they were naturally. In a later stage of civilization even estuaries are tamed in a similar manner. Mr. Lamplugh pointed out the following as some of the results of the taming of streams. Under the new conditions there is a more rapid transport of the finer waste to the sea, or lake, and presumably a heavier deposit of material on mudflats in the tidal estuaries, where the current is arrested. But sand, gravel, and boulders, pushed along the bottom of a stream, are removed by Man and usually put beyond the reach of further transport. Very generally these dredgings are used to raise the flood-banks, and so much detritus, naturally spread over a valley floor, becomes piled up close to the stabilized watercourse. When this process has been long continued there is often to be noted a slight, but well-defined, rise in the ground in the immediate neighbourhood of the river, on both sides; and in many cases the water-surface is considerably above the level of some of the alluvial floor of the valley. This condition is obviously unstable, and would soon be destroyed if Man's control were relaxed. On the whole, therefore, the natural deepen-

ing of valleys is checked, and in many places stopped; but the degradation of the land as a whole may be accelerated (since more detritus reaches the sea than under natural conditions).

The effect of drainage is well illustrated by the case of the Fenland. In Saxon and later times it was, according to Miller and Skertchley, " a vast open plain, covered for the most part with deep sedge, dotted with thickets of alder and willow, abounding in shallow lakes, temporary and permanent, and overflowed in its lowest parts, nearly, if not every winter. The fishing and fowling were valuable in the extreme, and the drier portions afforded a luxuriant pasture land."

Irrigation is the opposite to drainage; it is the artificial process of supplying water to crops in countries where the rainfall is either insufficient or comes at the wrong season for their cultivation. In the above sense irrigation scarcely exists in England. There are many cases where sewage is run on to the land, but the object in these cases is not to supplement a deficient water supply, but to dispose of sewage in the most harmless and profitable manner. If we consider the earth as a whole, however, irrigation is one of the most powerful agents used by Man.

In British India the area under crops in 1905 was 226,060,000 acres, and of these, 44,090,000 acres were irrigated, i.e. 19·5 per cent. of the whole. In the Indian Native States the area under sown crops was 71,070,000 acres and the proportion irrigated was 7,760,000, or 10·9 per cent. of the area sown.

Next to India the United States has probably the most extensive irrigation works. Some of these date back to prehistoric times. Near Mesa City, Salt River, one of the largest of these ancient canals had been excavated for several hundred feet, through hard volcanic rock, to a depth of from 20 to 30 feet. The rock showed signs of chipping, and great numbers of worn-out stone axes and hammers were found, an interesting instance of engineering by Stone Age man. The early Spanish settlers resorted to irrigation, but the first modern Americans to use it were the Mormons in 1847. All the more recent works in South California have been made since 1880.

The arid region of the United States is about two-fifths of the whole country, and the amount irrigable is from 60 to 100 million acres. The Reclamation Act of 1902 led to large projects, which were commenced in the following year. Up to June, 1917, the

United States Reclamation Service had constructed 9,970 miles of canals, besides numerous other works. The total excavation was 149,786,534 cubic yards, including 7,859,995 cubic yards of rock.

Of cement 2,741,763 barrels, of concrete 2,942,775 cubic yards, and "rip-rap" (stones thrown together without order) 1,527,920 cubic yards were used.

Irrigation was carried on in Egypt under the Pharaohs, though few traces of these early works now exist. Since English supervision commenced in 1884, great works have been carried out, including the Assuan dam, begun in 1888 and enlarged soon after completion, making its storage capacity 3,267 million cubic yards. Also, in the four years 1883–6 alone, there were earthworks erected in the Nile delta containing 9,275,000 cubic yards.

The largest artesian area in the world is in Australia, and comprises 569,000 square miles. Water was first struck in 1879 at Killara, in New South Wales. The supply comes from a porous sandstone of Triassic age. The intake comprises an area of 60,000 square miles in Queensland and 10,000 square miles in New South Wales, mostly mountainous country, and therefore usually free from drought. The bore-holes number 3,000

and maintain a daily flow of 480,485,000 gallons.

Waterways comprise rivers, canalized rivers (navigations), and canals. In England and Wales, according to the Canal Commission, there are 3,639 miles of canals and navigations, of which 1,927 miles are true canals. In addition, about 345 miles of canals have been converted into railways or are derelict. As the length of the rivers of England and Wales is about 7,929 miles, against 1,927 miles of existing canals, it appears that Man has added 24½ per cent. of new waterways to the natural streams.

Navigable rivers left in their natural condition are comparatively few, and those few are found for the most part in countries that are only partially civilized. Even the great Nile, flowing in the relatively unaltered continent of Africa, has been greatly modified. The difference between a canalized river, or navigation as it is called, and a canal, is that the latter is "an entirely artificial cut, which in many cases crosses the watersheds and river-basins at various levels. It requires that streams and watercourses be led to it or that mechanical means be employed to raise water to its summit and other reaches. A canalised river, on the other hand, is dependent only

on the river flow and not on any artificial means of supply." A canalized river follows in the main the course of some natural river and is in fact that river more or less improved for navigation. Sometimes the alterations are so extensive that the river is almost as artificial as a canal. The River Tyne is an example.

When Queen Victoria came to the throne the Tyne was in its natural condition. "It was a tortuous shallow stream, full of sand-banks and eccentric eddies which at Newcastle men might ford at low tide." In 1838 dredging began, and 21,379 tons were removed; in 1850 the amount was 66,452 tons. The Tyne Commission began work in 1851, and dredging became more vigorous, until in 1866 the maximum of 5,273,585 tons was removed. Including 5,000,000 tons from the Albert Edward Dock and some from the Northumberland Dock, 95,000,000 tons have been dredged from the river between 1838 and 1894 and deposited in the sea. In Shields Harbour a number of sand-banks have disappeared, and for a distance of 8,000 feet vessels can moor in over 30 feet of water at low-water spring tides. Bill Point, which was a cliff 72 feet high, protruding into midstream, has been cut back 400 feet from the point. This involved the

excavation of 2,000,000 tons of soil and rock, which were for the most part dumped in deep water. A new channel was made through Blaydon Haugh to cut off a loop.

Canals interfere greatly with the normal flow of water. The Grand Junction Canal is supplied with water from the basin of the River Colne at fifteen places. These fifteen canal feeders together drain 226,758 acres that would naturally have supplied the Colne. In some cases, as at Brent, the overflow from a reservoir feeds the river. The case of the Grand Junction Canal will serve to show how greatly a canal modifies the drainage of the district through which it passes.

Levées are embankments of earth thrown up to prevent the overflow of streams, or to stop the sea from inundating adjacent lands. They are first known to have been made by the ancient Egyptians and Babylonians. Levées are commonly seen in this country bordering rivers and estuaries that are liable to flood the bordering flats, but it is in other countries that they attain their chief development. By retaining the flood-waters a levée increases the height of the flood, and as the levée system is extended they require to be raised. According to General Comstock the bed of the river is

not raised, but the increasing height of the flood is due to the extension of the levée system, confining the flood-waters more and more closely. The scheme for the Mississippi required the building of 1,562¼ miles of levée, and 82 per cent. of this had been built by 1911. Up to that date 241,040,000 cubic yards of earth embankment had been made, and the complete scheme was expected to require 295 million cubic yards. There is an average annual loss by crevasses, caving in, etc., of 2¼ per cent. of the embankments. The area protected from flooding is 26,569 square miles. The rivers Theiss in Hungary, the Po in Italy, and the Loire, have also extensive levée systems. In Holland about 3,200,000 acres are protected against floods and also 210,000 acres reclaimed from lakes or the sea.

Since a levée prevents the low lands from being flooded, the silt that would normally be deposited on them by flood-waters and in time raise their level is carried into the sea, and so denudation is hastened by levées.

The earliest piped supply of water in Britain was established at Southampton, in 1420. In London there were conduits from the local springs, such as Clerkenwell, at an early date, for they are recorded by

Stow in 1598; but the first waterworks was founded at London Bridge in 1581, and in 1613 the New River was completed. So late as 1845 a Royal Commission reported that of 50 large provincial towns, only 6 had a good supply. Of the rest, 13 had an indifferent, and 31 a bad supply. In Birmingham only 8,000 out of 40,000 houses, at Norwich one-quarter, and in Newcastle only one-twelfth of the houses had separate supplies; while in Bristol, with 130,000 inhabitants, not more than 5,000 had a piped supply. For the most part people were supplied from stand-pipes or public wells. In 1849 the first report of the General Board of Health stated that it was the common practice to take as sources of supply the nearest river, stream, or collection of water, without regard for its quality.

It appears, therefore, that in early times Man's interference with the natural flow of water consisted mainly in taking water from rivers and springs, and that this water would find its way back, in a polluted condition, into the rivers, having suffered some reduction in quantity by evaporation. The size of streams would, therefore, not be markedly interfered with, although the water would be greatly polluted. We have to remember, in this connexion, that the population was

considerably less, and the quantity of water used per head very much less in early times than is now the case, and that both of these factors kept the amount of water taken from the streams a small one.

Many towns obtain their water from distant sources. The Manchester supply from Thirlmere is brought 96 miles; the Birmingham supply from the Elan Valley, 80 miles; the Liverpool supply from Vyrnwy, 66 miles, and from Rivington, 24½ miles; Leicester, Nottingham, Derby, and Sheffield obtain parts of their supplies from the headwaters of the Derwent (Derbyshire); all sources belonging geographically to other catchment areas.

The greater number of the unpiped supplies of the country are provided by wells, most of which derive their water from the subsoil. Springs, streams, rain-water, ditches, lakes, canals, and mines, also supply water.

All this water, no matter what its source, is lost to the rivers, for while streams and ditches supply rivers directly, underground supplies find their ways into rivers as springs. Pumping from wells reduces the underground water-level, thereby reducing or destroying the springs. Pumping from mines has the same effect, for once the mine cavity is filled, all surplus water will raise the water-level.

In the long run all water-supplies depend upon the rainfall. The average rainfall over England and Wales is about 32 inches per annum. Taking the area of the country at 58,186 square miles, the average total rainfall is 106,408,674,285 tons, or 23,835,543,040,000 gallons. T. Mellard Reade estimated an average of 13·7 inches evaporated annually from the surface of England and Wales. The remainder of the rainfall, or 18·3 inches, may be divided into two parts: that which runs off the surface and that which is absorbed by the ground, to reappear in course of time as springs. The water that runs off sweeps away loose materials into the stream and eventually into the sea, but has little opportunity for dissolving mineral substances; whereas the water that sinks in re-issues as clear spring water, free from sediment but containing substances dissolved from the rocks through which it has passed. The total amount of rainfall and the proportion that runs off, sinks in, or evaporates, are all modified by Man's activities. These interferences are referred to in the chapter on Climate (p. 208).

The quantity of water used by Man, in this country, has risen rapidly, but varies in a remarkable manner in different districts. A paper by W. A. Forbes gave the average

for urban districts in 1906 as 30 gallons, and H. B. Woodward, in 1910, gave 33 gallons per head per day as the average for the whole country. The Census of 1921 showed the population of England and Wales to be 37,886,699, so that the country uses about 456,345,289,455 gallons of water annually, or about 3 per cent. of the rainfall, after allowing for evaporation. This amount includes water used for domestic and trade purposes, and also that wasted, but in addition water is supplied to feed canals and steam-engines, for hydraulic power and for agriculture. What these further demands on water-supply amount to we do not know. One item, the loss by evaporation and leakage in the channels of British canals, is estimated at two inches of water per day, i.e. on 1,927 miles of canal of average width (42·5 feet at water-level) the yearly loss of water will be just over 2 million tons, or 448 million gallons. The waste of water at locks is not included. Again, in 1907, railways in England and Wales used over 10,000 million gallons, much of which came from wells.

The total amount of underground water supplied by piped services for domestic purposes has been put down as, very roughly, 285 million gallons daily, excluding supplies

from surface springs and water from stand-pipes. This amounts to 104,025 million gallons annually. Though not definitely stated (Return, Local Government Board), it appears that private wells are not included. The water pumped from underground sources must, therefore, be much greater than the figures given; for example, Clayton Beadle, in 1908, estimated that from 100 to 200 million gallons were taken daily from the London Basin alone by private persons.

H. B. Woodward estimated the water that runs off or that percolates at 10 inches per annum, whereas Mellard Reade estimated it at 18·3 inches. Here we take Reade's figures because he alone made elaborate calculations of the quantity of rock carried away in solution by rivers. Now the average amount of solids in solution in water from deep wells and borings is 41·5 grains per gallon (average of 28 analyses), and in spring water only 20·4 grains per gallon (average of 30 analyses). The difference is due to the fact that rain-water, when percolating into the ground, will not descend below the underground water-level (water-table); but on reaching that level will move laterally through the pervious rock until it escapes as a spring. There will be a very slight accession of substances in solution from the

stagnant water below the water-level, but such solids as the spring waters contain will be almost wholly derived from the soluble parts of the soil and the rocks above the water-table. This fact is well illustrated in rock-salt areas, e.g. Northwich, Cheshire, where springs containing a little salt have run for centuries, and yet more than one hundred times as much subsidence has been caused in ten years by the pumping of brine as was caused by natural springs in three centuries; because the only salt removed by springs was that which percolated upwards through the pores of the rocks from below the water-table. The effect of sinking a well and pumping is to cause the nearly stagnant water below the water-table to circulate. As it is pumped up, water runs in from round about and a current is produced towards the well. It is often noticed that the water pumped up from a deep well or boring is too highly charged with solids to be palatable or even drinkable, but after a time improves considerably. This is because the stagnant water within the space drained by the well has been pumped out and replaced by fresh water from above.

We see in the case of brine wells (p. 82) that pumping may greatly assist denudation,

and though less obviously true, the difference in the quantity of solids in solution in deep well-water and in spring-water points to the same fact.

We have seen that the underground water supplied by piped services for domestic consumption amounts to about 104,025 million gallons annually, with an average of 41·5 grains of solids dissolved in each gallon. The water therefore contains about 275,321 tons of solids in solution; whereas had the water been allowed to flow away naturally in springs containing 20·4 grains of solids to the gallon, it would have contained only 133,364 tons altogether. The difference between these figures is 139,957 tons, and this is the additional quantity removed in solution, in piped water supplies through Man's action. Put in another form, the additional quantity removed is about 72,985 cubic yards per annum.

It has been estimated that a million gallons of water pumped from the chalk contains $1\frac{1}{4}$ tons of chalk in solution, leaving a cavity of 17·6 cubic feet to be filled with water, unless subsidence occurs. In the water annually pumped from the chalk for piped domestic supply only, about 63,761 tons of chalk are dissolved, i.e. 897,753 cubic feet, or 33,250 cubic yards.

We shall probably be within the truth in allowing 115 million gallons daily for the water pumped up from private wells in addition to the 285 million gallons of piped supply. Taking the total underground water pumped at 400 million gallons daily, we find, by calculations similar to the above, that the additional amount of rock removed in solution by Man is 196,601 tons, or about 102,524 cubic yards, annually. Rock dissolved in water pumped from mines is additional.

The quantity of water used for domestic purposes has grown rapidly during the last half-century, and an increasingly large proportion of it has come from deep wells and impounded streams. The change from shallow to deep wells added appreciably to the loss by solution of mineral matter, for a shallow well affects only shallow underground waters that would otherwise find their way into rivers; while deep wells stir up the slowly moving or stagnant waters below the water-table. The increased solution of mineral matter now being effected is therefore of recent date. Although no real estimate of the amount of extra material removed can be given, we may assume that it will be not less than twenty years' loss at the present rate, or in round numbers

say 2,050,000 cubic yards of solids additional to that removed naturally.

The zone of weathering, i.e. the surface belt in which the rocks are affected by atmospheric agents, must be appreciably increased by mining, and by the pumping of water. Dry mines are few; usually they flood rapidly when left to themselves, and during active mining water is being constantly pumped from them. This produces a circulation of water, derived ultimately from rain, which has a powerful chemical and physical effect on the rocks. The strata mined may be naturally saturated with water which slowly escapes as spring-water; but in deep mines the strata are often found to be dry, partly on account of impervious beds above cutting off supplies of rain-water, and partly because the pressure packs the rock-particles too closely to allow room for much water. The excavations and the shattering of the strata above allow space for water to collect, and this is able to find its way down through the cracked rocks as well as through the shafts. The very impure character of mine waters is itself an indication of the weathering that is taking place below the level normally attacked. When mines are exhausted they become flooded, and if the water has no outlet it

becomes saturated with mineral matter and can then exert no further chemical action on the rocks. Sometimes an adit has been made, and if so there is a way for the water to escape, and it continues to circulate instead of stagnating.

Some interesting data relating to the South Staffordshire Coal-field were given by E. B. Marten in 1865. At that time the water raised daily from the mines was 50 millions of gallons (8 million cubic feet), i.e. a stream equal in volume to the River Tame. Marten speaks of the extremely corrosive nature of the water, which caused such rapid decay of the iron of the pumps and rods that in some cases the working barrels have needed to be constructed of brass.

To estimate the bulk of mineral matter removed in solution from mines by pumping, we require to know the average amount of solids in solution in mine-waters. There are singularly few analyses of such waters. As the differences are very wide, we shall here take the figures given in the Sixth Report of the Royal Commission on River Pollution. The Commission states that unpolluted water from deep wells in Coal-Measures contains, on the average, 0·0831 per cent. of total solids by weight.

We find that the water pumped from mines in one coal-field averaged ten times, in another fifteen, and in a third more than fifteen times the weight of coal raised. This would make the average weight of water pumped from collieries about twelve times the weight of coal raised. As the total weight of coal obtained in the United Kingdom from A.D. 1500 to 1928 inclusive is estimated at 16,166 million tons, the water pumped will amount to about 193,992 million tons.

It is to be noticed that in cases where the mine is drained by adits the denudation is the same as if the water were pumped, because the dissolved substances are poured into streams in both cases.

The average spring-water contains 20·4 grains per gallon, or 0·02914 per cent. of total solids, and we may assume that the difference in solid contents between mine-water and spring-water, or 0·05396 per cent. of the weight of water pumped, is the excess of solids removed in solution by Man's activities.

Taking the total amount of coal excavated in the United Kingdom since the earliest times to be 16,166 million tons, the water pumped to obtain it would contain, on the above reasoning, 51,463,000 cubic yards of

solids more than in the same quantity of spring-water, assuming that the solids had a specific gravity of 2·7.

Owing to the almost total absence of analyses of mine-waters I have no data for estimating the quantity of solids in solution in mines other than collieries. I shall therefore assume that their waters are similar in composition to those from collieries, and that they also have yielded 12 tons of water per ton of ore extracted, or a total of about 6,979 million tons of water. This quantity would contain 574,000 cubic yards of solids more than an equal volume of spring-water. Adding this to the figure for coal-mines we find that Man has removed in solution in water pumped from mines about 53,317,000 cubic yards in excess over the quantity that would have been removed naturally. Brine is omitted as the salt is extracted by the evaporation of the water.

Adding together the excess of solids removed in solution from mines and that removed from deep wells, we find that the total solids removed in solution by human agency is about 55⅓ million cubic yards to the end of 1928.

In places where the rocks are highly porous, as, for example, the outcrops of the Bunter and Chalk formations, the effect of

pumping from wells is sometimes to dry up small rivers. Cases have been examined by Mr. Urban A. Smith, in Hertfordshire, and brought before the notice of the Royal Commission on Metropolitan Water Supply. He stated, in 1893, that during the previous twenty years, all three heads of the River Colne had shrunk; the River Gade now rose 2 miles farther down its valley, the Bulbourne about $1\frac{1}{2}$ miles, the Chess about 2 miles, and the Ver about 5 or 6 miles, and other rivers had similarly shrunk. The same thing has been noticed near Nottingham, in the Bunter Sandstone country. The case of the Bulbourne is particularly interesting, because it has risen north of the Chiltern Hills within historic times, whereas the upper part of its former course now forms a so-called "wind-gap" (dry valley) in the Chilterns and has led to mistakes as to its age.

The drying up of streams in this manner is the result of pumping for water supplies. In many places the effect of pumping in lowering the water-table will have a considerable effect on land-drainage, for, if the water-table is lowered, there is an increased tendency for rain-water to sink in instead of running off.

Although irrigation is scarcely practised in Britain, engineering works of very similar

character to those of irrigated countries are constructed in connexion with water-supplies, whether intended for drinking purposes, for the supply of canals, or for driving machinery. The collection of the water by damming streams or sinking wells is carried out as if for irrigation.

The proportion of the area of Britain from which the drainage is collected is unknown. The collecting-areas for drinking-water are situated on sparsely inhabited moorlands, such as the Pennines, Dartmoor, Charnwood Forest, Wales, and the Lake District. But in addition to these supplies of pure water a great deal is collected to feed canals or drive machinery; and, since purity is not essential in such cases, these catchment areas frequently comprise inhabited districts. Moreover, the rain falling over towns runs off roofs and pavements into sewers, to that extent robbing the rivers of their natural supplies.

Water collected may be conducted through reservoirs and filtering appliances to pipes, and then distributed in some town many miles away. After use it passes into the drains and usually undergoes some purifying process before the residue that has escaped evaporation is poured into a river, canal, or the sea. If the water collected, or the sewage effluent, is put into a canal, it will find its way

to the sea after having actuated lock-gates. It is interesting to note that water taken from one catchment area, after use, not uncommonly enters the sea from another catchment area. Thus the waters of the Vyrnwy belong to the Severn system of drainage, but have been diverted to Liverpool, where they enter the Irish Sea instead of the Bristol Channel; again, the waters of Lake Thirlmere, instead of reaching the sea at Workington, Cumberland, are conducted to Manchester and finally enter the Mersey.

Water from a catchment area is made to run into a reservoir, where it deposits any detritus and issues as apparently clean water, even though it may be impure. Almost always compensation water has to be supplied to the river, robbed of part of its natural supply, otherwise, in dry weather, the water might fall too low to preserve the fish, or to work mill-wheels on its banks. Left to itself, the amount of water in a river will vary greatly at different seasons, and unless compensated the quantity taken, although scarcely noticeable in time of flood, might be the whole supply in the dry season. During rainy periods the reservoir holds up the water falling within its catchment-area and helps to prevent floods. On the other hand, in dry weather, by turning into the river a suitable

amount of water from the reservoir, the river is prevented from falling so low as it would do if left to Nature.

As reservoirs are numerous and the number is rapidly increasing, the effect on denudation must be considerable. There are 128 reservoirs in England and Wales for the supply of canals alone. Above the reservoirs, rain and floods will act as before Man interfered ; but the detritus washed away will be intercepted before it reaches the sea or the flood-plain, where normally it would be deposited. In the lower reaches, below the reservoir, the stream will run far more steadily than before, and is free from sediment, unless it picks up a new burden below the dam.

The " taming " of streams, as it has been called, greatly diminishes their eroding power. It has always been difficult to understand the amount of erosion accomplished by rivers when one watches the seemingly small effect of even a torrential stream in its ordinary condition. It is beginning to be realized that a great deal of erosion is performed in a cataclysmic manner after exceptional rainstorms. A cloud-burst may, in half an hour, dig a trench that twenty years of normal rainfall would have scarcely commenced.

Reservoirs offer protection to the valleys below them, for a flood exhausts itself in

filling up a reservoir and dumping there the burden of stones, or it may be trees, which are the chief weapons of attack. The reservoir may later overflow, but even then the stream below has had time to rid itself of its own surplus water before that above reaches it, and so a flood is prevented or reduced. Moreover, the water overflowing the reservoir is less than the original flood by the quantity needed to fill the reservoir, and the water has lost most of its destructive powers with its detrital burden.

The collection of water into reservoirs, i.e. artificial lakes, and the "taming" of rivers, tend to prevent floods, in opposition to the effect produced by the clearing of forests.

Pollution of rivers is largely a thing of the past, but the Reports of the Rivers Pollution Commission (1863), published from 1870–4, give a lurid account of the condition of British streams and rivers at that period. In colliery districts the "slack," long regarded as waste and often burnt, was sometimes tipped into a stream; but at the time of the Commission it was, to a great extent, washed, to free it from shale, which was allowed to silt up the rivers and cause floods, as below Staveley and Chesterfield, Derbyshire.

Of waters from other mining industries those from the lead "jiggins" were the most

objectionable. In flood-times the mud was spread over alluvial flats near Aberystwyth, Hexham, Matlock, and the upper tributary valleys of the Tees, Wear, and Clyde. At Aberystwyth and Machynlleth, the vegetation being killed, the soil, unprotected by grass, was washed away.

Of metal trades the most damage was done by the iron and steel wire, tinplate and galvanizing works, which employed sulphuric and hydrochloric acids to cleanse the metal. The liquids were poured into the sewers, often suddenly and in large volume, and being very acid dissolved mortar in the linings of the sewers. Brass foundries produced the same effect, but to a much less extent. The eroding effect of acids and other substances in solution in streams was strikingly brought out in the Sixth Report of the Commission. Mr. A. E. Fletcher estimated that in 1870 the free hydrochloric acid annually run to waste in the United Kingdom was 371,133 tons of commercial acid, equivalent to 111,400 tons of pure acid (HCl). This amounted to 45½ per cent. of the quantity made in the country.

The worst case of pollution from alkali works at that time was the Sankey Brook, near St. Helens, Lancashire, which could be smelt at a distance of from 1 to 2 miles.

The brook supplied the Sankey Canal, and it is recorded that the canal-water was so corrosive that the lock-gates had to be constructed entirely of wood. The canal received from one firm alone 500,000 gallons of 1 per cent. hydrochloric acid which destroyed the mortar, ironwork, and even the sandstone banks. Yet about twenty-five years previously, according to Mr. Atherton Selby, the Sankey Brook, that fed the canal, was fit for domestic use and contained fish.

Arsenic, in the form of arseniate of sodium, formerly escaped from dye-works. At the time of the Commission's investigation 400,000 tons of pyrites were annually imported and burnt for the manufacture of sulphuric acid. At a moderate computation this pyrites contained 1,600 tons of arsenic, a large proportion of which found its way into the rivers and streams. In addition, the soda-ash process, introduced into Britain in 1824, gave rise to the heaps of alkali-waste that are so noticeable near St. Helens, Widnes, Newcastle-on-Tyne, and in South Staffordshire. The quantity of sulphuretted hydrogen freed from Leblanc alkali-waste may be realized to some extent when we find that the heaps of waste at Widnes alone, estimated by Mr. E. Rhodes at 10 million tons, contained originally about 15 per cent.

of sulphur, whereas the weathered waste contains only about 0·938 per cent. From Widnes alone, therefore, about 1,400,000 tons of sulphur, mainly in the form of sulphuretted hydrogen, has found its way into the streams, either directly or via the rainfall. Other chemicals also were poured into the rivers and canals from the alkali and other works. The manganese dioxide used in the country at that period was about 54,000 tons annually, and this nearly all found its way into streams as manganese chloride.

At one time a great deal of sulphuric acid escaped into the atmosphere from works in the alkali districts, but this is no longer the case.

From soap-works, glycerine and common salt were the chief polluting agents, and at that time one firm at Widnes alone ran about 5 tons of glycerine (from 100 tons of fat) into the Mersey every week. Other trades were responsible for a variety of noxious substances.

Waters polluted by sewage are hard waters.

In the First Report, dated 1870, there is a detailed account of the pollution of the River Irwell, which separates Manchester from Salford. The Irwell and its tributaries were in the condition of common sewers. In

addition to sewage there was pollution by dye, print, bleach, chemical, woollen, and silk works, tanneries, and paper-mills. One print-works alone was estimated to pour into the river 500 million gallons of water annually, containing about 650 tons of solid matter in solution and 220 tons in suspension. The works employed 250 hands and was exceptionally careful.

At a thousand places along the Irwell and its tributaries mineral matter, much of it earthy waste, was thrown in. Many thousand tons of coal were burnt on its banks, and the ashes, roughly 12½ per cent. of the coal, were generally thrown into the stream. Between Albert Bridge and Throstlenest Weir the bed of the Irwell had risen, on the average, 1½ inches per annum since 1862. Elsewhere there were great shoals and obstructions.

The different kinds of substances polluting rivers have widely different effects on the capacity of the stream to erode, and to carry a burden in solution or suspension. Certain substances, such as soap, have an emulsifying action, and enable water to retain solid matter in suspension for a considerably increased period as compared with natural river-water. On the other hand, salts in solution cause suspended solids to be de-

posited. Briefly, we may say that substances that are electrolytes, i.e. which permit an electric current to pass through their solutions, cause solids in suspension to be deposited, while non-electrolytes tend to retain them in suspension. Both classes of substances will often be present together in polluted waters; in some cases one or the other type will greatly preponderate. There are as yet no data to enable one to estimate the nett effect on the turbidity of streams of the various kinds of pollution. In some cases the effect will be to carry the silt farther out to sea, before the salt-water causes it to be deposited, than would naturally be the case. In other cases, substances in solution may cause deposition on the river-bed and tend to choke up the stream. The complexity of the problem may be illustrated by the case of pollution from a soap-works. Formerly the chief substances added to the stream were glycerine and salt; but now glycerine is too valuable to be allowed to escape, and salt, being an electrolyte, has the opposite effect to soap on turbidity. Hence the effect of pollution by a soap-works is probably the opposite to what one might expect to be the case.

Soap, however, finds its way into the rivers, though not from soap-works. The quantity

used in the United Kingdom in 1907 was 352,750 tons, the whole of which, after use, would presumably find its way into the sewers. In the presence of a solution of soap all dissolved calcium salts, which are present more or less abundantly in all natural waters, are precipitated. Probably before a river reaches the sea all the soap it carries has been decomposed and replaced by organic salts of calcium (which are deposited on the bed together with entangled sediment), and solutions of sodium sulphate and perhaps chloride, according to the soluble salt of calcium originally present.

Mr. H. S. Williams, in his *Elements of the Geological Time-Scale*, says: "It may be a query worth considering, whether the estimates based upon the examination of the amount of suspended and dissolved matter in river-water are not likely to err in the direction of too small amount of matter by reason of the abnormal precipitation along the course of the river incident to the presence of salts and acids put into the river by Man. If the rate of the Po were taken the length of time [of the Geological Time-Scale] would be 73,000,000 of years instead of 680,000,000."

The practical effect of colloid organic matters is said, by A. Findlay, to be illus-

trated by the Rivers Mississippi, Nile, and Ohio. The two former are turbid, and contain much organic colloidal matter washed in with clay or soil, but this is deposited in bars and deltas. The Ohio is clear, except in flood-time, owing to the absence of colloidal matter and the presence of lime and other salts. F. W. Clarke, in the *Data of Geochemistry*, states that organic matter in natural water forms a flocculent precipitate with iron salts, carrying down, mechanically enclosed, the finest sediment.

The rivers became highly polluted probably between 1830 and 1840 and Parliament came to the rescue and suppressed much of the pollution about 1880. Hence the period of extreme pollution was probably limited to about thirty or forty years. After that time means were found to purify the streams and in many cases uses were found for the waste products.

It is doubtful to what extent Man's interference with the flow of water affects denudation. The material removed in solution is certainly increased. Land drainage tends to prevent flooding by offering an easy escape for water to the sea ; but agricultural operations tend to promote floods by causing the rain to run off the surface more rapidly than was the case under natural conditions. The

collection of water into reservoirs and the doling out of compensation water to the streams would appear to destroy their power of erosion; for a stream erodes its bed by sudden rushes of water after rainstorms and under the new conditions the streams have a uniform flow. Nevertheless, we must remember that the bulk of stream erosion is caused by mountain torrents, while reservoirs are placed below the torrents, collecting the water after it has exercised much of its erosive power.

Mr. G. W. Lamplugh concludes (*The Taming of Streams*) that there is an increased removal of fine material from the land to the sea, but on the other hand, coarse *débris* pushed along the bottom of the stream is artificially removed and is very generally used in raising the flood-banks. He concludes that the natural deepening of valleys is usually checked and in many places stopped, but nevertheless the degradation of the land surface as a whole may be accelerated. The main tendency is to flatten the land contours.

The effect of subsidence on drainage has been referred to in the chapter on Subsidence. One result is to lower the gradient of streams, thereby rendering them more sluggish and less capable of carrying sediment to the sea.

In low-lying districts swamps are frequently formed, e.g. round Wigan. In some cases the direction of drainage may be altered and waters find a new course to the sea.

CHAPTER IX

CLIMATE AND SCENERY

THE atmosphere is composed of three chief constituents: oxygen, nitrogen, and argon, with a variety of other gases present, some only as traces. Of the variable constituents carbon dioxide and water are by far the most important. The water present varies widely in amount, but the carbon dioxide only slightly, and except in towns and some other places it forms about 3 parts in 10,000 of air by volume. This apparently small quantity is really of vital importance, for it forms an essential foodstuff of green plants, and therefore indirectly of all animals, since every animal, directly or indirectly, lives on green plants. In addition carbon dioxide has a powerful effect on climate, because it has the property of absorbing heat reflected from the ground which would otherwise be radiated into space. Arrhenius thought that if the amount of carbon dioxide in the air were increased threefold, the temperature of the Arctic regions would rise by 8° or 9° C., and

similarly a reduction to about half or a third of its present amount might produce a glacial period. This leads us to speculate on the probable effect on climate when the carbon of coal and petroleum is restored to the atmosphere as carbon dioxide by combustion.

The atmosphere loses carbon dioxide mainly (1) by the growth of green plants, which decompose it into carbon and oxygen and retain the former element; (2) by the carbonation of minerals in the earth's crust. This latter action usually takes the form of replacing the silicates in such minerals as felspar, hornblende, and augite by carbonates. An additional quantity of carbon dioxide may combine with the carbonates of calcium and magnesium, thereby forming bicarbonates, which are removable in solution by rainwater. On the other hand, the atmosphere gains carbon dioxide (1) by the respiration of all animals and plants and by the decay of their dead bodies; (2) by the fact that when the normal carbonates of calcium and magnesium are reproduced by living beings such as corals, molluscs, and nullipores, which require them to build up their skeletons, half the carbon dioxide contained in the bicarbonates dissolved in sea-water is liberated; (3) by emission from volcanoes.

At the present time coal does not seem to

be forming anywhere, and although peat is growing in some countries it is decaying in others, e.g. Great Britain. This means that, no matter how much carbon is abstracted by green plants from the air, it is all restored on the death and decay of the plants, and of the animals and parasitic plants which all derive their substance from green plants. Hence the nett result on the atmosphere of animal and vegetable activities at the present time appears to be approximately nil.

Besides the enormous additions of carbon dioxide to the atmosphere made by the combustion of fuels, there are additional sources of increase due to Man. In clearing the land for cultivation enormous areas of forest are turned into arable or pastoral land. This must considerably diminish the total quantity of green-leaf surface, for it seems obvious that in a forest, where the land bears not only the trees with their masses of leaves, but also the undergrowth, as well as the mosses and lichens attached to the stems, there will be more green-leaf surface per acre than in a field of grass or crops, especially when a part of the ground is always fallow. The difference between the quantity of carbon locked up in the vegetation after clearing and that in the forest and undergrowth that formerly covered the same ground, is an addition to

the carbon dioxide in the atmosphere, for if the tree is burnt it goes back directly into the air, but if made use of as timber the return is only delayed for a relatively short period until the timber decays or is burnt.

Man has also interfered with animal life, and it might seem at first sight that the carbon dioxide given off by the respiration and decay of the 1,600 millions of human beings on the earth is a new addition to the supply; but although we cannot say just what changes in the animal population have been brought about by Man, it appears to be the case that the earth carries the largest mass of living creatures that it can support (hence the Struggle for Existence), and therefore the increase in the population of human and domestic animals probably coincides with the destruction of an equal weight of other animals, otherwise there would be a scarcity of food. On the whole, the destruction of forests and the consequent reduction in the quantity of plant-life will lead to a corresponding reduction in the quantity of animal life dependent on it for food.

The world's annual consumption of coal now exceeds 1,400 million tons, being 1,430 million tons in 1928. Taking the average percentage of carbon in coal as 84, and supposing that 4 per cent. remains unburnt in the ash,

then 1,144 million tons of carbon were burnt in 1928 to make 4,195 million tons of carbon dioxide, which passed into the atmosphere. This also receives a considerable amount of carbon dioxide from burnt petroleum. The first petroleum well was sunk in 1859, in the Appalachian Mountains. The first Russian well was sunk in 1871 at Baku. In 1928 the world's output was 181,100,000 tons and the total output of petroleum, up to 1928 inclusive, was about 2,387 million tons. The average percentage of carbon in petroleum is 86, so that the quantity of carbon dioxide added to the atmosphere by burning the above amount of oil is about 7,000 million tons. In reality this is far below the true amount, for there has been an appalling waste of oil and natural gas by fires at the wells, and the real figure is probably much greater. At three parts in 10,000 the carbon dioxide in the atmosphere amounts to about 2,200,000 million tons, equivalent to 600,000 million tons of carbon. At the present rate of consumption of coal and oil, which adds some 1,300 million tons of carbon to the air annually, it is clear that in about 461 years the carbon dioxide in the air would be doubled, and in 922 years trebled, bringing about the warm climate foretold by Arrhenius, unless there are means of re-

moval as yet unknown. Other effects of such an increase of carbon dioxide would be that (1) by the law of partial pressures, when the percentage of the gas is increased, the solubility in water is increased in like proportion, so that when the amount had been doubled the solubility in water would be doubled and rain would dissolve twice as much of the gas as at present, and its chemical action on soils and rocks would consequently be increased. This action would be aided by the increased rainfall following on the rise of temperature, for more carbon dioxide in the air means a more humid climate. Chemical denudation would therefore be increased and more calcium bicarbonate would be swept into the seas. (2) Animals and plants building their skeletons of calcium carbonate would probably be encouraged to multiply by the increased supply of raw material, and the formation of limestone would receive a stimulus. (3) There would be a physiological effect on air-breathing creatures. Presumably green plants would be stimulated by the warmth and by the increased food supply, and would grow more luxuriantly; on the other hand, the higher animals would probably be injuriously affected, although they would doubtless have been getting gradually acclimatized to the new conditions.

The effect of vegetation on climate has been described with great fullness by G. P. Marsh, whose book, *The Earth as Modified by Human Action*, is mainly devoted to the meteorological effect of forests and the results of their destruction by Man. This branch of the subject will therefore be treated very briefly.

Marsh gave reasons for thinking that the habitable earth was in all regions, with few exceptions, covered with forests when it first became the home of Man. He thought that even many parts of the African and Arabian deserts would soon be forest-covered if Man and his domestic animals, especially the camel, were banished.

It seems established that forests tend to mitigate extremes of temperature, humidity and drought. They protect the district to leeward from winds, e.g. the felling of woods on the west coast of Jutland has exposed the soil not only to drifting sand-dunes, but also to winds that have had a sensible deteriorating effect on the peninsula.

It is well known that forests maintain springs in permanent and regular flow, and consequently the streams fed by springs. Mosses and fungi growing on trees, and the dead leaves on the ground, act as sponges, absorbing the rain and giving it out gradu-

ally. The destruction of forests leads to the drying up of springs, and causes the streams to fail in dry seasons and inundate the country in wet weather. As it is during floods that streams do almost all of their mechanical erosion and transportation, destruction of forests leads to increased denudation.

All experience has shown that where land has been drained the rivers have become more irregular, with the exception of chalk-land, because chalk is very porous, and under-draining enables the chalk to absorb the rainfall more readily than before, and so prevents floods. Anything that increases the rapidity of flow assists the river to erode and to carry away the soil, and hence improvements in drainage increase denudation. Even in England indications of ravine formation, due to cultivation of the land, have been observed.

Professor Wollny experimented on three pieces of land sloping at 10°, 20°, and 30° respectively, and maintained them for a year without vegetation. He found that denudation was about sixty times as rapid on bare soil as on a grassy surface. Wollny suggests that trees would be still more effective than grass as a protection.

The destruction of forests has also led to

the formation of moving sand-dunes. In Russia, during the last thirty or forty years, many moving sands have originated which threaten to destroy the neighbouring cultivated lands. During storms in dry seasons the soil and subsoil is lifted by the wind and deposited against hedges, hollows in the ground, or in fact wherever the wind is more feeble. In some parts of Russia deposits form on the railways up to nearly 30 metres in height.

The countries east of the Adriatic—Idria, Dalmatia, Herzegovina, Montenegro, parts of Carniola and Croatia—have become by negligence deserts. The rainfall is very abundant, and part of Dalmatia and Herzegovina, at least, were once covered with forests, which were cut down to build the Venetian navies. Cattle destroyed the young shoots, and humus, deprived of the protection of the trees, was washed away by rain, and the limestone below laid bare. Rain falling on this runs into the fissures, and, the rock being soluble, funnels are formed by which the rains discharge themselves very quickly into subterranean streams, leaving the country a desert.

Marsh has pointed out the striking difference between the condition of the countries of the Mediterranean and the Near East at

the time of the Roman Empire and now. Then, these countries were fertile and prosperous; now more than half the area is either a desert or is greatly reduced in both population and productiveness. Northern Africa, Arabia, Syria, Armenia, Asia Minor, Mesopotamia, Persia, and even parts of Italy and Spain, once rich agricultural lands, are now unproductive. The explanation given is, firstly, ignorance of Nature's laws, and secondly, bad government and civil wars.

One effect of a forest is to lower the temperature of the district. This effect is mainly due to the evaporation of water by the leaves of the trees, which absorb heat in the process. In cleared areas the formation of ravines increases the temperature locally in two ways, firstly, by facilitating the drainage and thereby drying the soil; and, secondly, by allowing the air, chilled by contact with the soil at night and in winter, to flow away. A plateau dissected by ravines is therefore warmer than before dissection.

Forests not only offer protection from winds but this action incidentally increases the rainfall, for W. Koeppen has shown that a gentle wind allows the air in motion time to be thoroughly chilled and so causes the moisture contained to fall as rain. In this manner, as well as by keeping the air humid,

forests increase the rainfall. These actions are modified by Man cutting down or planting trees. Every change in the surface of the land, as well as drainage, irrigation, and the working of arable land, all modify the climate. One of the most important factors is the cultivation of rice. This cereal, which forms the staple food of hundreds of millions of human beings, is grown in artificial marshes. Natural marshes are usually covered with high vegetation which protects the water-surface from the sun's rays; but the shallow water on the rice-fields, which cover an immense area in India, Indo-China, China, Java, and Japan, is strongly heated by the sun's rays. Many rice-fields were dry districts before Man took them in hand; now they are kept humid by the great evaporation. Woeikof thinks that the prolongation of the monsoons towards autumn is in part due to evaporation from the rice-fields.

Britain in pre-Roman times was an inhospitable land, almost covered by woods, moors, and fens. Although it had been inhabited for thousands of years, primitive Man probably produced little or no effect on the aspect of the country. The Romans no doubt altered the primeval appearance to a considerable extent along the lines of their roads; nevertheless, from the account of

England as it was in the sixth century, at the time of the Anglo-Saxon invasion, given by J. R. Green in *The Making of England*, the country was then still in a very unsettled condition. After the Romans had departed Britain relapsed, to a considerable extent, into its primitive condition. The roads made by the Romans decayed and others were mere tracks, the maximum deterioration being reached about the beginning of the sixteenth century. Some account has already been given of the condition of the roads in early days.

Apart from a few mountainous regions such as parts of the Scottish Highlands, which may retain their original aspect to a considerable extent, the scenery of Britain has been completely altered. The general enclosure of land must have transformed the countryside, while the growth of the towns and of industries during the last hundred years, with the necessary accessories of paved roads, railways, canals, reservoirs, etc., must have caused Britain to present an appearance that would be utterly strange to a man of the Middle Ages, could he revisit the country.

The characteristic scenery of a coal and iron district may be seen in the region known as the Black Country, lying between Wolverhampton and Birmingham. If, for example,

one takes a walk from Wolverhampton to Wednesfield, one crosses a wild-looking and barren waste, divided by a few fences or dilapidated hedges, but broken up by railways, canals, and an occasional road. Grimy clumps of cottages occur at intervals, and one has distant views of tall chimneys, while over all is a smoky sky, which, however, gives rise to fine sunsets. Remains of the original surface are seen here and there between accumulations of colliery-waste and slag. The mounds are of every size and shape, though as a rule they are flat-topped, rising about 15 to 25 feet above the natural surface-level, and covering from one to many acres. In some parts the mounds are entirely composed of black shale broken into small fragments, in others the material is largely slag, sometimes in craggy masses several yards across. Special industries have locally added waste of unusual kinds, as, for example, chemical waste. Bits of brick and rubbish of every kind are seen scattered over the ground. Here and there ponds covered by green algæ fill hollows sometimes 40 feet below the surrounding level.

Perhaps the natural scenery resembling this black desert most closely will be found in districts that have suffered from an outpouring of lava and scoriæ, before there has been

time for the rocks to decay and be covered by vegetation.

The slate industry of North Wales has also had a marked effect on the scenery. At Blaenau Ffestiniog, and elsewhere, the mountains are covered with talus-fans, made of fragments of slate from the mines, to a height of over 1,000 feet. So enormous is the quantity of slate excavated that Professor Davis has estimated the human denudation in Snowdonia as equal in amount to all the natural denudation that has been effected in the district since the Glacial Epoch.

Few parts of Britain have escaped radical changes in aspect. Even a barren moor like Dartmoor has been transformed ; for at one time it was covered by trees. These were cut down to smelt the tin-ore, and owing to lack of shelter from the winds the moor has remained bare ever since.

Dartmoor serves to illustrate another remarkable change in scenery. The area of the moorland is now about half of what it was when it was a forest reserved for hunting. Gradually it has been enclosed, piece by piece, drained, and the loose stones picked off and built into walls. The contrast between the open moor covered with loose stones and the smooth pasture inside the walls is very striking, and enables us to realize to some

extent the great change brought about by Man in the aspect of Britain. We have referred on page 60 to the extent to which loose stones have been built into walls or broken up for road-metal. In earlier days they were tumbled into ruts in the roads without being broken.

In the chapter on Subsidence instances have been given where swamps have been formed in consequence of mining operations. At Northwich there are scenes reminiscent of the Western Front. Swamps are well marked round Wigan, but not many miles away we may see the reclamation of a bog, for the famous Chat Moss, which offered such a tremendous problem to George Stephenson, when making his first railway, has mostly been reclaimed by filling it up with the refuse of Manchester. The former bog is now solid land fit for agriculture.

The rubbish from towns is to an increasing extent being burnt in destructors, and the clinker made into paving blocks, or concrete. In these cases the effect on the scenery is negligible. In other cases, however, the waste is dumped in some convenient quarry or valley, and there it forms terraces. Almost every town offers illustrations of this, even where a destructor is now installed. Also there is, of course, trade refuse not

suitable for a destructor. As the waste is carted, or transported on rails, and then dumped, a flat is formed, with a steep edge of which the inclination is the angle of repose of the material. The flat grows in area as the point at top of the original cone extends into a surface, but the marginal slope retains its inclination. When the waste is tipped into a deep valley a second or a third flat may be formed upon the first one. In valleys the flats have somewhat the appearance of river-terraces and the imitation becomes more marked when plants have covered the rubbish.

Usually roads along river-valleys are raised more or less above the river level, to prevent flooding, and the terraces of rubbish usually grow out from the road as the material is tipped from carts until a flat that may be many acres in extent is formed at the road level, and in time this is likely to be built on.

Quarries vary greatly in shape, but in a majority of cases they are cut out of elevated ground, with a flat floor. Even where the rock is dug out below the level of the approach road the hollow is often filled up, at a later date, by waste material, whether from the quarry or from an adjacent town. The resemblance of a horseshoe-shaped quarry in a hillside to a coombe, corrie, or cwm, caused

by glacial action, is striking; although the quarry is usually on a much smaller scale. There is the same precipitous wall diminishing to nothing in front in both cases. Where the quarry is situated some distance up a hill-slope which is continued below the floor, we get a further resemblance.

When the quarry, or mine-adit, is in a steep hillside, the waste material is usually thrown down at the entrance and forms a talus-fan similar to a natural fan formed at the mouth of a torrential stream. In time a more or less extensive terrace is built out opposite the quarry. Some quarries are dug out of flattish ground to a considerable depth, and in that case the result is a cavity with approximately vertical walls. Usually the cost of obtaining stone at increasingly great depths and the difficulty of keeping out water, or a failure in the demand for stone, cause the quarry to be abandoned. After remaining derelict for a period, probably partially filled with water, it is likely to be filled up with refuse and to disappear.

Embankments and cuttings are striking features in a landscape. The former have counterparts in Nature in eskers, moraines, and kames, left by the Great Ice Age; the latter in certain dry valleys cut by water escaping from lakes dammed by glaciers.

Lakes are characteristic of glaciated countries, and with few exceptions are confined to them. Man, however, is also a lake-maker ; water is ponded up in valleys or on flats for various purposes, and the larger of these are quite comparable in size with natural lakes. Thus Vyrnwy, an artificial Welsh lake, is larger than any natural lake in Wales. In various ways the influence of Man on Scenery is more like that of Ice than of any other agent.

It will be noticed that the general effect of Man is to level down hills and fill up hollows, thereby producing a succession of terraces. A type of terrace that deserves mention here, because although not common in England it is one of the most striking relics of early Man, is the cultivation terrace. These lynchets, as they are called, are benches cut in a hillside too steep for cultivation. The step-like terraces enable soil to remain on the hillside instead of being washed away by rain. They are very well seen from the former London and North-Western Railway on the west side of the line after passing through the Tring cutting. They are cut into chalk on the southern face of Southend Hill.

There is a tendency for terraces to be destroyed at a later date, and the final effect of human activities would probably be, if

there were no counteracting agents, to produce a flat surface falling uniformly and very gently towards the sea, a peneplain in fact such as atmospheric agents tend to produce. Of course it is highly improbable that natural forces will be quiescent sufficiently long for this result to be reached, but it is interesting to note that, using different methods, Man arrives at the same end as Nature.

The great changes of scenery brought about by the introduction of new plants are biological effects of human interference and therefore do not fall within the scope of this work.

CHAPTER X

CONCLUSIONS

IN this chapter I propose to gather up the threads and see what general inferences can be drawn from the facts set out in the preceding pages.

We are so accustomed to steadiness in Nature that we assume that she always acts with deliberation and never varies her methods. For example, we assume that a valley has been dug out by the river now flowing down it, although there is no deepening visibly in progress. We draw a big draft on time, and put back the age of the valley by a sufficient number of thousands or millions of years to give the river an opportunity of doing the work. We are, however, beginning to realize that under climatic conditions different from the present ones, and such as occurred in and after the Great Ice Age, the valley could be scooped out in a comparatively short time, and that at present the rate of denudation has slowed down. It becomes apparent, also, that such

deepening as is even now being effected is the result of exceptional storms producing torrents that sweep away more material in a day than the river normally moves in half a century. Such instances indicate that Man has exaggerated the steadiness of Nature, and that a succession of small catastrophes alternating with steady periods is the truer idea. Spread over a geological period, minor catastrophes are not apparent, just as to an observer in an aeroplane minor irregularities in the earth's surface disappear and a false idea of flatness is obtained. It may be correct that the formation of 10,000 feet of rock belonging to one geological period represents about the same lapse of time as was required for the same thickness of rock during another geological period, and yet a closer investigation might show great variations in the speed of accumulation of different parts of the rock masses.

From this viewpoint the work of Man resembles that of natural agents that are known to have acted with exceptional power at intervals in the earth's history, e.g. the action of ice is purely natural and constantly with us, and yet the intervals between the three or four Ice Ages that have occurred are measured in millions of years. To the men who lived during the last Ice Age the con-

ditions must have seemed the natural state of things, although to us they are difficult to conceive. The differences between the purely natural conditions of denudation and accumulation, when tropical animals and plants lived in what is now England, and the time that followed, when the country was in the condition of Greenland, were at least as great as any changed conditions wrought by Man. Moreover, it has been shown above that the actions of Man have been, so far, limited to a much briefer period than that of an Ice Age, and although we cannot say how long human interference will last, it is evident that Man's geological work varies frequently, and that he undoes to-day much that was done yesterday, thereby considerably diminishing his nett activities.

A marked characteristic, then, of Man's action on Nature is its intermittency : while his geological activities grow in power they are for ever changing their direction. For instance, the rate at which road-pavements are being worn out is such that, if continued through a geological period, the denudation would be enormous ; but in point of fact the rate has increased from a very small figure, before the nineteenth century, to its present amount, and already there are indications that the rapid introduction of organic

materials for pavements has checked the advance, and may soon diminish the rate at which the inorganic materials are being destroyed. Here, therefore, the period at which the rate of denudation is high is limited, and may prove to be less than a century.

A similar unsteadiness is apparent in the effects of Man's activities. Instead of producing a flat or smooth curving surface he makes the ground very uneven, producing terraces, holes, and mounds, in a most sporadic manner. In its geological effects human work resembles that of a glacier more than any other natural agent. The morainic material called " kettle drift " bears some resemblance to the waste-heaps left by Man; eskers and kames produced by ice often closely resemble embankments in outward aspect, and may dam up water into lakes in a similar manner. Again, as has been pointed out already, the denudation of pavements has a nearer resemblance to the graving of ice than to any other natural agent. Quarries bear frequently a close resemblance to coombes and corries, made by glaciers; railway- and canal-cuttings resemble certain glacially cut channels; glaciers and Man alike frequently abrade unweathered rocks. Finally, the period of

the Great Ice Age was, geologically speaking, a short one, and although we now know that there have been several Ice Ages, yet in their occasional character they resemble the work of Man.

A very important point of difference between natural and human denudation is the extent to which it is carried. If we examine a conglomerate such as one of those in the Bunter formation, we find that it often contains exceedingly hard pebbles, as, for example, the well-known quartzite pebbles of the Bunter. The original formations from which the pebbles are derived are often Pre-Cambrian or Older Palæozoic, i.e. the oldest rocks known. An individual pebble is often utilized over and over again in rock-making. A quartzite pebble in the Glacial Drift is often derived from the destruction of a Bunter conglomerate, which in turn may have derived it from a Devonian conglomerate, destroyed at the time of formation of the Bunter rocks. The pebble may contain an Ordovician fossil, showing that in Devonian times it was already a hard rock. Lastly, Professor Garwood has found quartzite pebbles, exactly like typical Bunter pebbles, in Pre-Cambrian conglomerate, so that some of the pebbles must have existed in exactly their present form at the most remote period of geo-

logical history. No doubt each time the rock in which the fragment lay has been denuded the pebble was slightly reduced in size, but a hard quartzite pebble is almost everlasting; at least its life may be hundreds of millions of years. When, however, Man uses such pebbles for road-making the stones lose their identity. The road will presently be taken up and re-made, but the pebbles, now worn flat on one side, can be used again and again, and lying in a new position, will have another flat surface worn on them. The pebble is finally reduced to a small size, the greater part of it having been triturated into the finest dust. The hard banket of Johannesburg, a conglomerate of quartz pebbles, is ground to a fine powder, pebbles and matrix alike, in order to free the particles of gold.

In Nature, trituration occurs by the action of waves, rivers, ice, and wind; and also in volcanic eruptions. It is usually accompanied by chemical changes, so that soils, the normal result of atmospheric denuding agents, are not simply powdered rocks, but differ considerably from the parent mass. For example, an igneous rock exposed to the action of the air has its felspars decomposed with the formation of "clay"; the potash and soda being to a considerable extent dissolved out, the ferrous compounds are decom-

posed by the oxidation and hydration of the iron, and carbonates replace silicates in part. By these changes the rock becomes incoherent, and passes, by stages, through rubble into soil, which is destined to be washed away into the sea, where it is sorted into sand and clay, and deposited. When the same igneous rock is quarried by Man for road-metal he rejects the outer partially decayed rock and uses the hard, unaltered inner parts, which he proceeds to reduce to powder by mechanical and not by chemical means. The dust, therefore, has approximately the composition of the original rocky mass and differs widely from the clay produced by natural agents.

Another important difference between natural and human denudation is that natural denudation removes by preference the softer and more easily destroyed rocks, and so the less resistant form valleys while the more resistant make ridges and plateaux. If the difference in destructibility is great, the shape of the ground is rugged in proportion, and so we find wild crags, composed of massive igneous rocks, set amongst softer materials. Man, however, selects for excavation such rocks as will be of economic value, or which are obstacles in the way of his projects. Thus rocks will, regardless of

their nature, be removed to make room for railways or roads, or to reach stable foundations. In other cases a hard igneous mass will be quarried for road-metal or building-stone and the surrounding soft rocks left untouched, e.g. in Charnwood Forest. In these cases Man makes a hole where Nature intended a hill. At other times a loose sand or a brick-earth may be selected for quarrying. We may notice that Man does not ignore the resisting powers of rock, for if it is reasonably easy to avoid cutting through a hard rock to make a railway he will do so; at other times, as in the case of a road-metal, he deliberately selects hard rocks for excavation.

We found that the total excavation by Man in Great Britain to the end of 1913 was of the order of 40,000 million cubic yards of rock, which if taken uniformly from the surface of the British Isles would be equivalent to the removal of a layer 3·83 inches in thickness. Omitting Ireland, from which a small but unknown additional amount has been excavated, the layer would be 5·24 inches. The excavation, of course, is not uniformly spread, and the bulk excavated in Scotland north of the Firths of Forth and Clyde would be inappreciable compared with the volume excavated south of that line.

We may therefore imagine the total excavation to be concentrated in England, Wales, and the thirteen most southerly counties of Scotland; that is approximately the whole of Great Britain south of the Clyde and Forth; or on an area of 65,226 square miles. On this area the material removed is equivalent to a layer of rock 7·12 inches in thickness.

Next we may divide the total excavation into that below ground (mines) and that above ground. Apart from tunnels, wells, and borings, all the forms of excavation in the table on page 37 may be added to the amount from quarries to give the total of surface excavation. The quantity of material removed in tunnels, wells, and borings can only be guessed at. That it is very considerable is indicated by the figures on page 100, which show that within London alone the Tube Railways and Inner Circle were responsible for the excavation of 11,262,000 cubic yards. We shall assume that the total of such excavation amounts to 308 million cubic yards; this being the amount required to make the 19,692 millions obtained from mines into the round sum of 20,000 million cubic yards. Hence the total excavation from below the ground is about equal to that from open excavations at the surface.

Here we may remark that G. W. Lamplugh (in *On the Taming of Streams*) came to the conclusion that Man's geological activities worked, on the whole, with gravitation. It appears, however, that this is not the case in Great Britain, for the total material brought up from mines, against gravitation, is approximately equal in bulk to that dug out at the surface, and which, on the whole, is moved to lower levels. These figures refer to Man's total work since the earliest times, but the vast bulk of the work was done by modern Man, and during the nineteen years ending 1913 the rock mined was about six times as much as that quarried.

Although the total amount of rock excavated is equal to a layer 7·12 inches in thickness, this is not the amount by which the country south of the Forth and Clyde has been lowered, on the average, for we must remember that the rock mined produces a subsidence equal to only a fraction of itself. We have given the fraction the average value of 30 per cent. and therefore the lowering of the surface will be, not 7·12 inches in all, but 3·56 inches due to surface excavation, and 30 per cent. of 3·56 inches from subsidence caused by mining, or a total of about 5·628 inches in about two thousand years, which is about 0·2814 inches per century.

The remaining volume excavated, namely, 14,000 million cubic yards (i.e. 70 per cent. of 20,000 millions), remains as spaces in the earth's crust. To this must be added a large part of the 43 million cubic yards of minute spaces left by the removal of rock in solution from mines and deep wells (up to 1913).

Let us now compare these figures with the rate of natural erosion. Sir Archibald Geikie, in his *Text-Book of Geology*, states that the rivers mentioned below remove rock from the general surfaces of their basins in the following ratios : the Mississippi removes one foot in 6,000 years ; the Danube in 6,846 years ; the Po in 729 years. At the Mississippi's rate of denudation North America, assuming the average height to be 748 feet, would be reduced to sea-level in about 4½ million years. On the other hand, Europe, with a mean height of 671 feet, would be worn down to sea-level in less than half a million years, if denuded at the rate the Po denudes its basin. Geikie estimated that for the British Isles the rate of planation is about one foot in 8,800 years. These figures do not include the loss in solution, estimated by T. Mellard Reade at approximately one-third that removed in the solid form ; but it is pointed out that the loss by solution does not necessarily lower the level to the

same extent as rock planed off the surface, because much of the dissolved rock is removed from subterranean sources.

The rate of planation of the British Isles given by Geikie, namely, a foot in 8,800 years, is equivalent to 2·72 inches in 2,000 years, or less than half that due to Man during the same period. We have found, however, that by far the greater part of Man's work was done during the last century, and it follows that at the present time, in a densely peopled country like England, Man is many times more powerful, as an agent of denudation, than all the atmospheric denuding forces combined.

It may be thought that in estimating the rate of human denudation we have forgotten to allow for human accumulation. In Chapter VI we have shown that Man is a rock-maker as well as a rock-destroyer. Nevertheless, accumulation is small compared with denudation. Consider, for example, that of the coal excavated only the ash remains, the rest has disappeared into the atmosphere. The metal iron, representing about 35 per cent. by weight of the iron-stone won, rusts and disappears, and the other metals also vanish in various ways. Even gold, which never corrodes and owing to its high value is carefully preserved, disappears.

Much quarried material is rubbed away on roads and by other means reduced to dust, which readily finds its way into rivers and so into the sea.

In the case of bricks and pottery a soft clay is burnt into a hard rock, but we have seen (p. 150) that after about sixty years, on the average, this material passes in a fragmentary condition into "made ground," where it is mixed with masonry, concrete, slag, and every other product of human activity that has survived decay. "Made ground" is itself an incoherent and superficial deposit, analogous in texture and position to a river deposit or glacial drift. We know that river and drift deposits are almost unknown in past geological periods, owing to the feeble resistance they offer to denudation, although in an exceptional case, as when a sheet of lava has flowed over a terrace, it may be preserved. We conclude therefore that, geologically speaking, Man acts as a denuding agent, and that his accumulations are temporary and not to be offset against the material excavated, when considering the rate of human denudation.

The rate of denudation by the Mississippi is usually taken as the standard for rivers, because the area drained by the river is so large that it includes all kinds of land and

a large variety of climates; but it is in marked contrast to the rate of other rivers, e.g. the Po and the Hoang-Ho. All have been tamed by Man and we do not seem to possess reliable data of the rate of denudation by large rivers still in the natural condition. The Congo and Amazon basins are scarcely touched by Man, but both rivers flow through vast tropical forests. They might, however, be compared with such rivers as the Lena and Mackenzie, which flow through Arctic lands, and the average of the two types might give a better average figure for the untamed river than does the Mississippi.

It is very important to geologists to find the average rate of denudation of the land under natural, as distinct from artificial, conditions, for geological chronology is based largely on these figures. The differences between the rates of the Mississippi, Hoang-Ho, and Po are startling, and it seems highly probable that, until the influence of Man on denudation has been more completely studied and allowance made for it, calculations of geological time may be far from the truth, the errors tending probably to give a period much too small.

The effect of Man on the coast appears to be, on the whole, protective; judging

from the fact that during the thirty-five years ending 1911 the British Isles have increased in area by 41,362 acres. It is probable that it is only in recent times that the land area has been increased; for reclamation and protective works are almost all modern, while, until a generation or two ago, destruction was caused by the removal of shingle. At present it is not possible to say if recent gains are greater than the losses that took place during many preceding centuries.

We found that Man's works on the coast have all been dependent on the accident that we live in a period of earth quiescence. So recently as 4,000 years ago there was a marked subsidence, and Reid has pointed out that a rise or fall of the land amounting to only a few feet would have disastrous effect on all our coastal works as well as seriously disturb the inland drainage. This is a good indication of the impermanence of human efforts.

The amount of geological change brought about by Man will depend on two factors, firstly the density of population, and secondly the degree of engineering energy shown. Both factors have been increasing in value since prehistoric times.

The population of England at the time of

Domesday Book was about two millions; it increased slowly and reached perhaps four millions in 1348, when the Black Death destroyed from one-third to one-half of the people, and a succession of wars and pestilences kept the population from increasing again until Tudor times. About 1830 the rate of increase became accelerated.

As regards the second factor, the increase in engineering activity, the same thing happened in a more marked degree, as is well brought out by Louis D'A. Jackson in *Four Centuries of Engineering Progress.*

The table on page 19 showing the production of pig-iron at different dates illustrates the remarkable increase in engineering energy, for the output of pig-iron is an indicator of the amount of work done. From 17,350 tons produced in 1740 to 581,367 tons in 1825 is a marked increase, but in 1840 the output had jumped to 1,396,400 tons following the introduction of railways, and in 1900 had grown to 8,959,691 tons. An increasing population naturally required an increasing output of iron, but while the population had multiplied about five times between 1740 and 1900 the iron output had multiplied about five hundred and sixteen times, showing the enormous increase in engineering activities. It is to be remem-

bered, however, that iron was being imported when the British rate was small, and so the rate of increase may not be quite so marked as appears.

The increase in the population was caused almost entirely by the growth of the towns. It has been estimated that the population working on the land when Domesday Book was compiled was much the same as now. Omitting Middlesex and Surrey, which contain London, the growth in density of population is most marked in the case of Lancashire, which in 1700 was not one of the first ten counties in order of population, but in 1881 was easily first of all; this of course being due to the growth of industries. The purely agricultural counties, such as Buckinghamshire, Rutland, and Oxfordshire, have not altered much in population for many centuries; although even here small towns have added slightly to its density.

The population of England and Wales was divided at the dates stated, as follows:

	Rural Districts.	Percentage of Population in Rural Districts.	Urban Districts.
1851 .	8,936,800	49·8	8,990,809
1881 .	8,683,026	33·3	17,285,026
1911 .	7,907,556	21·9	28,162,936

In 1377, according to A. P. Usher, England contained 9 towns with more than 5,000

inhabitants, including 3 with over 10,000 (London 37,302, York 11,597, Bristol 10,152); also 11 towns with 3,000 to 4,999; 19 with from 1,000 to 2,999; and 3 towns with less than 1,000. Compare these figures with the preliminary figures of the 1921 Census which give 46 towns with more than 100,000 inhabitants and also 55 with more than 50,000!

The development of the towns has caused Man's geological activities to grow by leaps and bounds. Increased population and engineering activity react on one another as a mutual spur, for a greater density of population requires the exercise of engineering skill to provide the necessary water, transport, lighting, and sanitation; as well as factories in which the people may earn their bread. These increased facilities cause a further growth in the population, which means still further demands on the engineer. This is the reason why the growth of population and of industry were so slow for centuries, before certain key inventions caused an increasing acceleration in both, until the population began to be too great for the area of the country to support without outside assistance. Industrial depression and emigration then came into action and the growth in the British population became comparatively small from these causes.

Increasing population means increased artificial denudation by attrition of the ground and by excavation of useful minerals ; it also means an increased area covered by buildings and roads and therefore protected from natural denudation. The increasing number of domestic animals also had an effect, although this was chiefly biological and therefore beyond our scope.

In addition to direct denudation Man causes indirect denudation by modifying climate. We have seen that desert conditions have been brought about in many parts of the world by the destruction of forests, and that, as a result, disastrous floods have swept away soil and dug deep ravines on cultivated lands. The denudation so caused is an unknown quantity, but even in Britain it is noticeable, while if the whole earth is considered the rock removed by these floods doubtless adds considerably to the rate of human denudation. To some extent irrigation, which reclaims desert regions, has helped to prevent denudation, but has not balanced the destructive forces.

Another result of human activity is more doubtful and at present is in the speculative stage. We have referred to the possibility of a considerable increase in the amount of carbon dioxide in the atmosphere as the

result of the burning of fuel, and the probable effect on climate of such an increase if it occurs. The effect is likely to be in some degree inimical to the higher animals, and therefore to favour lower forms of life in the "struggle for existence"; and also to raise the average temperature of the earth. A more distinctly geological result would be an increase in the rate of denudation, for not only would more limestone be dissolved in a given time, but the ordinary processes of decay by atmospheric chemical action would be accelerated.

Truly it would seem as if "Man strews the earth with ruin." But this conclusion is too flattering to human vanity. Man's most permanent memorial is a rubbish-heap, and even that is doomed to be obliterated.

Perhaps the most difficult, and at the same time the most interesting, problem that arises in connexion with our subject is the relation between Man's psychology and his geological activities. His most profound interferences with Nature have their origin in his thoughts, and it is the changes in Man's ideas that are responsible for the intermittency of his activities.

One or two instances will illustrate what may result from a change in fashion. At one time buildings were roofed with a

variety of materials: straw, tiles, or local flag-stones; but in course of time the value of slate was discovered, and this material almost entirely superseded the others. From a geological point of view this meant that instead of clay or flag-stone being quarried, enormous excavations were made in hard slate rocks. At present there is a prevalent idea that a tiled roof is more artistic than a slate one, with the geological result that clay is excavated instead of a corresponding quantity of slate. Again, the thoughts of such men as Brindley, the constructor of canals; of Telford, the road-maker; of George Stephenson, the locomotive builder, have had marked geological results, as is shown in the preceding pages. We are in the habit of distinguishing human activities as "artificial" as distinct from "natural," or those of Nature; and it seems very extraordinary that natural processes can apparently be interfered with by something outside Nature, i.e. by Man's thoughts.

The difficulty diminishes, or disappears, if we realize that our distinction between "artificial" and "natural" is unreal. We must remember that all living things produce geological effects, and that there is a gradation between the apparently mechanical work of the lower organisms and the deliber-

ate acts of Man. Primitive Man's action on Nature was similar in character and degree to that of many other animals. During the early Stone Age Man's geological work consisted in chipping a few flints; beating a few pathways through the wilderness; and leaving behind him a few small heaps of burnt stones, literally his pot-boilers. Still more primitive Man did not know how to make a fire, or to shape a flint-implement, and was in all things like the beasts. The elephant and the buffalo were more effective pathway-makers, and the white ant surpassed him as a builder. Where, then, shall we draw a boundary between the works of Man and that of other animals? The beaver builds dams and reservoirs in an intelligent manner, and is more of an engineer than some living races of men. Is, then, the beaver's work natural or artificial? It is the result of directed intelligence as much as is the Nile Dam or the Vyrnwy Reservoir. Moreover, the beaver is not even one of the higher mammalia, but a relative of the rat and the rabbit. Clearly the so-called artificial is but a form of natural action, and so we must consider all Man's geological work to be as essentially natural as the work of the sea or of the atmosphere, but differing in the relatively

very brief period of activity. Because of the brevity of the period Man's work will sink into insignificance when viewed as part of geological history. Nevertheless, during the present short chapter of that history Man's work is very important, and as worthy of a place in geological text-books as are the actions of the sea or the rivers.

If we compare Man's influence on the earth with that of other animals and plants, it is probably no greater than that of some organic agents of the past. So far as we know, the lands, during the early geological ages, were either bare or covered only by such simple plants as algæ (plants such as the *Protococcus*, which forms the green patches on tree-trunks), although some of these may have attained to a considerable size. When the Coal-measures flora had been evolved the land was completely changed, for the dense jungles in which coal was formed extended over a great part of the Northern Hemisphere. The conditions of sedimentation and denudation must have been revolutionized by the growth of these plants, and, moreover, it is probable that the climate of the whole globe was fundamentally altered (see p. 208) by the removal of a vast mass of carbon from the atmosphere. The geological effect of plant life during the Coal-

measures period was at least equal to that of Man, and no one would deny its purely "natural" character, or see in the growth of coal, and all it involves, any interference with Nature by Life.

In spite of variations in the mode of attack, it seems that the rate of human denudation, as a whole, has been increasing rapidly until the present time. An interesting question is, will the rate continue to increase, or even be maintained at its present level, in the future? There are indications of diminution before long. The increasing price and scarcity of coal are likely to compel the utilization of other forms of power, and the first to be utilized will probably be water-power. The scheme for damming the Severn is a sign that the time has almost come for such projects, though not necessarily large schemes. Most of our rivers exhibit instances of power running to waste. Each weir at present represents waste energy, but the time will probably soon come when a small turbine will be attached to each small fall and electricity produced for local uses, such as lighting adjacent houses or pumping water from wells. When this change has been effected the rate of denudation will be greatly reduced, for we have seen that coal-mining is one of the chief forms of human

denudation, and the water-power will take the place of coal to a greater or less extent. Secondly, the denudation due to rivers should be greatly diminished, for it is at falls that the rivers are most effective in erosion. Increased protection of the sea-coast may also be expected, and so, on the whole, the prospect is that the present tendency of human interference to hasten denudation may shortly be replaced by an opposite tendency. This is in accordance with our idea of the impermanence of human geological activities.

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